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OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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VOL. 30 NOVEMBER 1908 NUMBER 10

THE monthly meeting for November will be held in the Engineering Societies Building on the evening of November 10. A lecture will be given upon The High Powered Rifle and its Ammunition, by Franklin Phillips, president of the Hewes and Phillips Iron Works, Newark, N. J., and Inspector of Small Arms Practice, National Guard of New Jersey.

For a long period following the famous matches at Creedmoor, long distance rifle shooting by American marksmen was to a considerable extent a lost art and when American teams participated in international matches they failed to win. Finally a number of interested riflemen began a scientific study of the causes of inaccuracy in shooting and investigations were conducted in which means were adopted for making accurate comparisons of results at target trials.

Mr. Phillips will trace the development of the rifle and its ammunition, explaining details of construction, and many lantern slides will be exhibited showing these details as well as the actual use of the rifle by experts. The art of rifle shooting at the present time is comprised in hitting fast rather than shooting fast. An occasional erratic shot through some defect in gun, bullet or powder is not to be tolerated. The lecturer will show how some of these defects have been overcome.

ANNUAL MEETING

TO BE HELD IN NEW YORK, DECEMBER 1–4

In this number of The Journal are published four additional papers for the annual meeting, making the published list to date as follows:

The Engineer and The People, by Morris Llewellyn Cooke.

Liquid Tachometers, by Amasa Trowbridge.

A Method of Obtaining Ratios of Specific Heats of Vapors, by A. R. Dodge.

An Averaging Instrument for Polar Diagrams, by Prof. W. F. Durand.

The Slipping Point of Rolled Boiler Tube Joints, by Prof. O. P. Hood and Prof. G. L. Christensen.

Some Possibilities of the Gasolene Turbine, by Prof. Frank C. Wagner.

Salt Manufacture, by George B. Willcox.

Efficiency Tests of Milling Cutters and Milling Machines, by A. L. DeLeeuw.

Physical Properties of Carbonic Acid and Conditions of its Economic Storage for Transportation, by Prof. R. T. Stewart.

The Total Heat of Saturated Steam, by Dr. H. N. Davis

Industrial Photography, by S. Ashton Hand.

It is expected that by the time this number of The Journal is issued all the papers for the annual meeting will be in hand for the consideration of the Meetings Committee; and as far as possible the balance of the papers will be published in the Mid-November number in order to give members time to prepare their discussions before the meeting.

MACHINE SHOP PAPERS

In this number are two papers for the annual meeting of unusual importance to builders of machinery: one by Mr. DeLeeuw upon tests conducted by him preliminary to the design of a new series of milling machines, and the other by Mr. Hand upon Industrial Photography. Besides these there will be other contributions of extraordinary interest upon cutting tools and recent developments in spur

gearing, the whole comprising a list of strong papers bearing directly on the design and construction of machinery, with due regard for the commercial as well as the purely technical sides. While the work of the mechanical engineer has broadened out into many fields, such subjects are peculiarly within his province. However diversified his work in individual instances, he is bound to be interested in improved methods for the production of machinery. These papers will be grouped and used for a session upon machine shop practice, and as the papers will deal almost entirely with new developments, no member can afford to miss this session, if he is within reaching distance of New York at the time of the annual meeting.

OTHER PAPERS

While the subjects for the balance of the papers cannot be definitely announced at this time, there are several papers under consideration that will attract very wide attention and will be remarkable additions to the store of printed information upon engineering topics. The complete program will be published in the next number with full information about these, as well as upon the entertainment to be provided by the local membership for the visiting members and their guests.

AERONAUTICS

On Wednesday morning, December 2, there will be the paper upon Aeronautics by Major Squier, Acting Chief Signal Officer, Washington, D. C., about which particulars have already been given, and we desire to impress upon members the fact that this paper, together with the popular lecture upon the same subject by Lieutenant Lahm, to be given Wednesday evening, will form the most important and striking presentation of aeronautics that has been given in this country.

This is the first time that aeronautics has been considered by any of the national engineering societies of America. It is only now that the science of flying by mechanical means has been developed to the point where it would be thought advisable to place a record of the achievement and a statement of problems involved in the publications of an American engineering society. In taking this important step, the Society is to be congratulated on having its material from so authoritative a source and presented by engineers so unbiased

and able as the two officers who are to appear before it at the December meeting. The data, photographs and drawings placed at the disposal of the Society for these papers are obtained through the courtesy of the War Department, where every bit of obtainable information upon aeronautics is on file, not only in respect to the work accomplished by the government and individuals in this country, but by governments and individuals abroad.

RAILROAD TRANSPORTATION NOTICE

Special concessions have been secured for members and guests attending the Annual Meeting in New York, December 1–4, 1908. Read carefully the following details.

The special rate of a fare and three-fifths for the round trip, on the certificate plan, is granted when the regular fare is 75 cents and upwards, from territory specified below.

a Buy your ticket at full fare for the going journey, between November 27 and December 3 inclusive. At the same time request a certificate, *not a receipt*. This ticket and certificate should be secured at least half an hour before the departure of the train.

b Certificates are not kept at all stations. Find out from your station agent whether he has certificates and through tickets. If not, he will tell you the nearest station where they can be obtained. Buy a local ticket to that point, and there get your certificate and through ticket.

c On arrival at the meeting, present your certificate to Mr. S. Edgar Whitaker at the Headquarters. A fee of 25 cents will be collected for each certificate validated. No certificate can be validated after December 4.

d An agent of the Trunk Line Association will validate certificates December 2, 3 and 4. No refund of fare will be made on account of failure to have certificate validated.

e One hundred certificates must be presented for validation before the plan is operative. This makes it important to ask for certificate, and to turn it in at Headquarters. Even though you may not use it this will help others to secure the reduced rate.

f If certificate is validated, a return ticket to destination can be purchased, up to December 8, on the same route over which the purchaser came, at three-fifths the rate.

This special rate is granted only for the following:

The Trunk Line Association:

All of New York east of a line running from Buffalo to Sal-

amanca, all of Pennsylvania east of the Ohio River, all of New Jersey, Delaware and Maryland; also that portion of West Virginia and Virginia north of a line running through Huntington, Charleston, White Sulphur Springs, Charlottesville and Washington, D. C.

The Central Passenger Association:

The portion of Illinois south of a line from Chicago through Peoria to Keokuk and east of the Mississippi River, the States of Indiana, and Ohio, the portion of Pennsylvania and New York north and west of the Ohio River, Salamanca and Buffalo, and that portion of Michigan between Lakes Michigan and Huron.

MEETING OF THE COUNCIL

A regular meeting of the Council was held on the afternoon of Tuesday, October 13, in the Council room of the Society, 29 West 39th Street, New York.

The meeting was called to order at 3.30 p.m., with Vice-President P. W. Gates in the chair. There were present: Messrs. P. W. Gates, John W. Lieb, Jr., Fred J. Miller, Wm. H. Wiley, the Secretary, and Past-Presidents C. W. Hunt, Ambrose Swasey and Fred W. Taylor.

MEMBERSHIP

The Secretary reported the following deaths: H. W. Cake, S. B. Cox, Fred N. Fowler, F. A. Johnson, F. N. Kleinhans, F. X. McGowan, Wm. Anson Pearson, E. F. Schaefer, Jos. Stone, Harris Tabor.

The Council directed that the Secretary send to the estate of a deceased member a marked copy of The Journal containing the memorial notice of such member.

RESIGNATIONS

The following resignations were accepted by the Council: Chas. C. King, E. B. Guthrie, E. E. Hanna.

CANDIDATES FOR MEMBERSHIP

The Candidates shown by the Professional Service Sheet of September, 1908, were approved and the names were ordered submitted to the voting membership. The ballot will close November 25, 1908.

FINANCES

The balance of unexpended appropriations, $2700.99, upon the recommendation of the Finance Committee, was ordered cancelled.

Budget 1908–1909: The consideration of the budget of 1908–1909 was deferred until the next meeting. The Council ordered trans-

ferred to Profit and Loss $830.16 unexpended appropriations for the year 1906–1907.

COMMITTEES

Conservation Committee:—The Council approved the appointment of the Committee on Conservation of the Natural Resources of the Country, the personnel of which is as follows, George F. Swain, *Chairman*, L. D. Burlingame, Chas Whiting Baker, M. L. Holman, Calvin W. Rice, and requested that the Committee outline to the Council before the next meeting, the scope of the work which they recommend that the Society undertake.

Library:—The Council approved the recommendation that permission be granted the Secretary, upon the recommendation of the Librarian and the Chairman of the Library Committee, to dispose of the duplicate periodicals and books secured by virtue of the joint operation of the three libraries, the proceeds of the sale to be credited to the appropriation for the Library Committee.

Publication: The Publication Committee reported Volume 29 on the press and Volume 30 well advanced.

STANDARDS

International Standard Pipe Threads: The Secretary reported to the Council the recommendations of the special committee, consisting of Messrs. E. M. Herr, *Chairman*, George M. Bond, Wm. J. Baldwin and Stanley G. Flagg, appointed to report on an international standard for pipe threads and fittings.

The Secretary was requested to give the substance of this report to the American Gas Institute which has invited the Society to assist in preparing an argument in favor of the Briggs Standard to be presented at the conference in Paris, January 1, 1909.

Standard Tests of Refrigerating Machines: The Secretary reported a communication from the chairman of the committee of the Society appointed to report on a standard tonnage basis for refrigeration, recommending that the committee prepare a joint report with the committee of the American Society of Refrigerating Engineers on Standardization of Tests of Refrigerating Machines. The recommendation was approved.

Code for Conducting Steam Boiler Trials: The matter was referred to a special committee to consist of Mr. John W. Lieb, Jr., and Mr. Fred W. Taylor.

REPLICA OF THE THURSTON MEMORIAL

The Secretary was most happy to receive from the chairman of the committee of the alumni of Sibley College, Cornell University, permission to have a replica made of the tablet of Prof. R. H. Thurston, recently erected at Cornell. The sculptor of the Memorial, Mr. H. A. McNeil, has consented to make the tablet.

A committee was formed several years ago to secure funds for a memorial in bronze of Professor Thurston. The subscriptions received at that time are almost sufficient for the tablet.

The Council thereupon voted to erect the tablet in the building of the Engineering societies, and appointed the following committee to supervise the work: Dr. Alex. C. Humphreys, *Chairman*, Messrs. Charles Wallace Hunt and Fred J. Miller.

A photograph of the tablet was published in the October 1 issue of The Journal.

SIR BENJAMIN BAKER MEMORIAL

The Secretary reported having sent to the Institute of Civil Engineers of Great Britain a subscription of $155 from members of the Council toward the memorial window to Sir Benjamin Baker, Honorary Member of the Society, to be erected in Westminster Abbey.

COURTESIES TO OTHER SOCIETIES

The Council voted to join with the American Society of Refrigerating Engineers in tendering the use of the building of the Engineering Societies in the event that the International Congress of Refrigerating Industries should hold its Congress in this building next year.

The Secretary reported that the Society had extended through Honorary Councillor Mr. Ambrose Swasey the courtesies of the rooms and library of the Society to the following engineering institutions in Great Britain, and that most cordial acknowledgments had been received: The Institution of Electrical Engineers, The Institution of Mechanical Engineers, The Institution of Civil Engineers, the Iron and Steel Institute.

GENERAL NOTES

A MEMBER OF THE SOCIETY HONORED

King Edward VII has recently conferred Knighthood upon Mr. Robert A. Hadfield, member of the Society and chairman and managing director of the Hadfield Co., Sheffield, England, in recognition of his valuable services in the field of industrial and scientific progress through his researches and experiments in metallurgy, and his invention of manganese steel.

At the meeting of the Iron and Steel Institute held in New York, Oct. 3, 1890, Mr. Hadfield presented a paper on "Aluminum Steel" after which the President, Sir James Kitson, now Lord Airedale, proposed that the thanks of the meeting be tendered him for his continued generosity in giving to the Institute the results of his valuable research and labor, and nominated him for a seat in the council. The proposal and nomination were unanimously voted.

He has also received, on different occasions, honors from the following scientific societies: From The Institution of Civil Engineers in 1888, the Telford gold medal and premium; and in 1899 the George Stephenson gold medal and premium. In recognition of his researches on the subject of manganese steel the Franklin Institute of Philadelphia presented him in 1891 with the John Scott legacy medal and premium; La Société d'Encouragement pour l'Industrie Nationale presented him with a gold medal in 1890 and another in 1895. In 1903 Sir Robert received the Howard Prize and premium awarded by the Institution of Civil Engineers quinquennially. Former recipients of this prize were Sir Henry Bessemer, Sir William Siemens, and Sir Lowthian Bell; The Iron and Steel Institutute awarded him the Bessemer gold medal in 1904.

Sir Robert's contributions to the science of metallurgy are: "Manganese in its Application to Metallurgy" (manganese steel); "Some Newly Discovered Properties of Iron and Manganese;" "Manganese Steel;" "Alloys of Iron and Silicon;" "Alloys of Iron and Aluminum;" "Alloys of Iron and Tungsten."

A GIFT TO THE SOCIETY

Mr. Henry Harrison Suplee, Chairman of the Library Committee of this Society, has made a gift to the library of sixty volumes of valuable technical books. A complete list is published in this issue of The Journal under Acquisitions to the Library. The thanks of the Society are due to Mr. Suplee for his liberality in adding to the reference resources of the library.

NEEDS OF THE LIBRARY

The Library needs several volumes of periodicals to complete its valuable sets and the attention of the membership is called to the list published among the advertising pages in this issue of The Journal. The Secretary will be very glad to hear from any member who can provide any of the books there mentioned, either by gift, purchase or exchange, and by helping to complete these sets a valuable service will be rendered to the Library and therefore to the Society.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

The American Institute of Electrical Engineers held a meeting on Friday, Oct. 9, in the Engineering Societies Building at which a paper entitled High Potential Underground Transmission was presented by Messrs. P. Junkersfeld and E. O. Schweitzer. The paper described a 9000 volt and a 20 000 volt 3-phase cable main of the Commonwealth Edison Co., of Chicago. It was discussed by Messrs. Chas. H. Merz (London, England), E. J. Berg, Wallace Clark and others.

THE AMERICAN INSTITUTE OF MINING ENGINEERS

The American Institute of Mining Engineers held their annual meeting Oct. 8, in Chattanooga, Tenn., with headquarters at Hotel Patten. Professional sessions were held Thursday, Friday and Saturday, after which those attending the convention visited the mines and furnaces of the Roane Iron Co., at Rockwood, Tenn., the mines at Copper Hill and Ducktown, and the mines, smelters and sulphuric acid plants of the Tennessee Copper Co. and the Ducktown Sulphur, Copper and Iron Co., at Knoxville. Before returning home several went to Birmingham to inspect the mines there.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS

The American Society of Civil Engineers held a meeting in New York, Oct. 7, at which a paper was presented by Mr. O. F. Liford, Jr., of the Westinghouse, Church Kerr & Co., on Catenary Trolley Construction. The paper was a description of the construction employed in the electrification of the Denver & International Railroad, running from Denver to Boulder, Colo.

THE ILLUMINATING ENGINEERING SOCIETY

The Illuminating Engineering Society held their second annual convention in Philadelphia, Oct. 5 and 6. An address was made by the President, Dr. Louis Bell of Boston, in which he emphasized the practical side of street lighting, advocating greater diffusion, decreased brilliancy, better distribution and more light, and a number of papers were read relating to the subject of illumination.

The committee on standards presented a report of the progress toward securing an "international candle" or unit of light strength. The appointment of a joint committee by the American Institute of Electrical Engineers, American Gas Institute and the Illuminating Engineering Society was reported. The resolutions adopted by this joint committee were in favor of a unit of candle power which would be a compromise between the units used in gas and electric lamp photometry in this country, as being close to the mean value of the units used in the national laboratories in this country, England and France. They advocate the use of the unit in this country during the intervals required for the consummation of international action that would be 2 per cent less than that now used by the bureau of standards.

INTERNATIONAL CONGRESS OF REFRIGERATING INDUSTRIES

The First International Congress of Refrigerating Industries was held in Paris, France, October 5 to 10. The University of Paris generously placed the Sorbonne at the service of the convention, and the sessions were held in its auditorium.

The congress was under the official patronage of the Republic. M. Emile Loubet, ex-president of the French Republic, and M. de Freycinet, member of the Institute, senator and ex-minister, were the chairmen of the Committee of Honor, which was composed of about 50 ex-ministers, members of the Institute, governors-general of colonies, officials of the administrations, presidents of important press associations, presidents of large scientific, agricultural, industrial and commercial societies, presidents of chambers of commerce, presidents of colleges and presidents of large transportation companies.

M. André Lebon, ex-minister of commerce, ex-minister of colonies, was the president of the executive committee of the congress, and M. Touchard, the distinguished Secretary-General of Credit Foncier of France, treasurer.

Representatives were delegated to the congress from L'Académie des Sciences, L'Académie de Médecin, Les Conseils Généraux, institutions of learning, scientific, industrial, agricultural and commercial associations of France and other countries.

The members of the Society participating were Mr. John E. Starr, Vice-President of the American Committee of the Congress, and Mr. Gardner T. Voorhees appointed Honorary Vice-President of the Society for the occasion, and papers were contributed by the following members: Messrs. John E. Starr, Gardner T. Voorhees, D. S. Jacobus.

In addition, the following countries sent special delegates: Austria, Bavaria, Denmark, Hungary, Italy, the Grand Duchy of Luxembourg, Norway, Russia, the Netherlands, Servia, Switzerland, Turkey; America; the Argentine Republic, Brazil, the United States, Paraguay, Uruguay; Asia and Oceanica; China, Japan, Queensland, Tas-

mania, Victoria, Australia, New Zealand. The United States was officially represented by delegates appointed by the Secretary of State and the Secretary of Agriculture.

The first section, of which M. D'Arsonval, member of the Institute, and professor at the College de France, was president, considered Low Temperatures and their General Effects. The following papers were read:

Effects of Low Temperatures and their Action, Physical, Chemical and Biological, by M. Georges Claude; General Hygiene, showing advantages and disadvantages of refrigeration in public and private places, by Dr. Bordas; Alimentary Hygiene, treating of the dietetic value of chilled and frozen food, by Dr. Navarre.

The second section, of which M. H. Leaute, member of the Institute, and professor of the École Polytechnique, was president, discussed Refrigerating Appliances. The following papers were read:

Refrigerating Machinery, Standardization of Refrigerating Measures and Employment of Dry and Wet Refrigeration, by M. A. Barrier; Standardization of Refrigerating Measures, by D. S. Jacobus; The Construction of Cold Stores, Insulating Materials, Refrigeration in Magazines for Explosives and Refrigeration in Packing Houses, by Dr. Imbeaux.

The third section, of which M. A. Gautier, member of the Institute, and president of the Académie de Médecin, was president, considered The Application of Refrigeration to Food. The following papers were read:

Changes in Produce while in Cold Storage Chambers, by Dr. Regnard; Colonial Produce Capable of Benefiting by Refrigeration, by M. J. Chailley, Artificial Cold in the Manufacture of Butter, by M. P. Rouvier; Cold Storage Organization, by M. Maurice Quentin; Victualing of Besieged Towns and of Troops, by M. G. Chapuis; Sea Fisheries and Refrigeration, by M. H. deVarigny.

The fourth section, of which M. E. Tisserand, of the Institute, and Honorary Director of Agriculture, was president, discussed The Application of Refrigeration to Other Industries. The papers were:

Retardation and Preservation of Flowering Plants by the Application of Cold, by M. Ph. de Vilmorin; Influence of Refrigeration on the Clarification of Fermented Beverages, by M. A. Fernbach; Ice-making, by M. P. Fabry; Mines, Metallurgy, Public Works; New Industrial Applications of Refrigeration, by M. D. Saladin.

The fifth section, of which M. Levasseur, member of the Institute, and Director of the College de France, was president, considered Application of Refrigeration in Commerce and Transport. The papers were:

Progress of Trade in Perishable Produce, by M. D. Perouse; Organization of Cold Storage Transport on Railways, by M. G. de Pellerin de Latouche; Organization of Cold Storage Transport by Sea, by M. J. Dal Piaz.

The sixth section of which M. J. Cruppi, Deputy, Vice-President of the Chamber of Deputies, was president, considered Legislation. The papers were:

Laws and Regulations to be Modified, by M. J. Lauraine; The Value of Refrigeration in the Food Supply of the Poorer Classes, by M. M. Saint-Germain.

During the afternoons of the congress, excursions were made to various industrial plants about Paris among which were the plant for the manufacture of liquid air by the process discovered by M. Georges Claude, the ice factory of Villan Court, the works of La Société des Glacières, Paris, L'Institut Pasteur, the works of La Société d'Eléctricité de Paris at Saint Denis, the refrigerating plants of the packing houses of La Villette and La Conservatoire des Arts et Métiers. An excursion to Fontainebleau was a pleasant event. The foreign groups—German, English, Spanish and Italian were accompanied by a guide who spoke the language of the party.

A banquet was given as a fitting close of a very delightful event. M. André Lebon presided. It was characterized by simplicity, and *cachet de fête de famille,* remarkable where all countries and languages were represented. Delegates from all the foreign governments had the pleasure of seeing their national colors decorate the table of honor.

Several toasts were given at the close of the banquet, M. Lebon, the president, lifting his glass in honor of the kings and presidents of the countries represented. The second toast was to the hospitality of the City of Paris, and in closing M. Tellier, who may be termed the originator of the congress, was saluted. A résumé of the Refrigerating Congress was given in a word: "We have worked for something which endures. *C'est là toute la philosophie.*"

The General von Vendrich, minister of Roads and Communications of Russia, offered a toast to the City of Paris in the name of the delegates from the North and M. Samarelli, Italian Under-Secretary of State, in behalf of the delegates from the South.

M. Tellier, in a short address, thanked M. Lebon for his courteous compliments. He said in closing: "God is the power. Man can only try to reduce the effects of the terrible forces of nature."

The closing session of the congress was devoted to resolutions and

farewell addresses. M. Chéron, Sous-Secrétaire d'Etat, presided. Short addresses were made by M. Lebon, president of the congress, and by M. Chéron, followed by a scholarly and philosophical address on liquid air by M. d'Arsonval.

The next International Congress of Refrigerating Industries will be held in Vienna in 1910 and the third congress will probably be held in the United States.

The importance of the inauguration of an international congress of refrigeration cannot well be estimated. That it will have its influence upon the economic conditions of all the countries of the world cannot be doubted. It is a cause for national pride that the United States is leading the world in the development of refrigeration, and this country should take advantage of the disposition, manifested at the congress, to hold the third convention here.

The Society acknowledges the thoughtfulness of Mr. Voorhees in regularly sending reports of the Congress, from which the above was translated.

PAN-AMERICAN SCIENTIFIC CONGRESS

The first Pan-American Scientific Congress will be held in Santiago, Chile, Dec. 25, 1908, to Jan. 5, 1909, under the auspices of the government of Chile. Universities, scientific societies, Chilian and foreign corporations will be represented. Questions of interest to South, Central and North America will be discussed. The broad scope of the Congress is shown by the subjects for discussion, among which are pure and applied mathematics, physical sciences, natural, anthropological and ethnological sciences, engineering, medical science and hygiene, juridical and social sciences, the sciences of pedagogy and of philosophy, agronomy and zoötechnics. Americans who have become prominent in the field of science will represent their several countries at the Congress.

The Society, through the Secretary, has been assisting the delegation of the United States to secure the papers on engineering, to which an entire section has been devoted. The papers, prepared by men whose names will be recognized at once as carrying authority in the world of engineering, have been transmitted to the International Bureau of American Republics for translation and transmission. They are as follows:

MEMBERS OF THE SOCIETY

William H. Burr, C.E., professor of civil engineering at Columbia University, "Reinforced Concrete Construction for South America."

William Kent, A.M., M.E., "Economy of Fuel."

Charles E. Lucke, M.S., Ph.D., head of department of mechanical engineering, Columbia University, "The Value of Gas Power."

R. M. Dixon, M.E., president of The Safety Car Heating and Lighting Co., New York, "Car Lighting in North America."

William Hutton Blauvelt, M.E., M.S., consulting engineer, Semet-Solvay Co., Syracuse, N. Y., "The Use of Tertiary Coal in General Metallurgy and in the Manufacture of Coke."

Rudolph Hering, hydraulic and sanitary engineer, "The Supply of Potable Water."

NON-MEMBERS

J. F. Kemp, M.E., Sc.D., professor of geology, Columbia University, New York, "The Newer Geological Views regarding Subterranean Waters."

William J. Wilgus, chief engineer of construction and maintenance of way, and vice-president, N. Y. C. & H. R. R. R., "Plans and Gages of Inter-Continental Railways."

Frank J. Sprague, electrical engineer, "Application of Electricity to Railways."

C. O. Mailloux, consulting electrical engineer, "Terminologia Pan-Americana."

Robert Hallowell Richards, S.B., Mass. Institute of Technology, "Processes for the Concentration of Ores."

William S. Myers, M.Sc., director Chilian Nitrate Propaganda, "American Agriculture in its Relation to Chilian Nitrate."

Allen Hazen, civil engineer, "Water Supply of Cities and Towns."

R. W. Raymond, Ph.D., LL.D., secretary of the American Institute of Mining Engineers, "The Mineral Wealth of America."

Walter R. Ingalls, editor, the Engineering and Mining Journal, New York, in collaboration with Dr. R. W. Raymond, "The Mineral Wealth of America."

The Chilian government has requested the United States to send delegates, and the invitation was met in a fraternal spirit which portends well for the movement of international conciliation, now being fostered.

The following delegates were appointed by the State Department of the Government:

L. S. Rowe, *Chairman*, Hiram Bingham, Archibald Cary Coolidge, William C. Gorgas, U. S. A., W. H. Holmes, Paul S. Reinsch, *Vice-Chairman*, Bernard Moses, George M. Rommel, William R. Shepherd, William Benjamin Smith.

EDUCATIONAL COÖPERATION

The possibilities of educational coöperation between North and South America have received a scant measure of consideration in this country. Prof. L. S. Rowe, LL.D., Professor of Political Science in the University of Pennsylvania, chairman of the delegation from the United States, who may be called the missionary of our educational system in the Southern Americas has emphasized our responsibility toward the American Republics. He states that it is evident to every one who has watched the national feeling in South America that the time has come when we must view our position on this continent with a keener sense of the responsibilities which it involves, and shape our policies with a view to our future as well as our present standing among our neighbors. The South American people have a feeling of admiration for the wonderful progress of our country and a sincere desire to profit by it. This new spirit finds distinct expression in the almost universal demand for American teachers and American educational methods. Dr. Rowe gives three possible lines of activity for developing educational coöperation: First, the better preparation of American teachers for service abroad, and the cultivation on the part of the teachers of a spirit of adaptability, from which results a ready sympathy with a people whose point of view is different from our own. Second, a concerted effort to attract a larger number of South American students to our normal schools and universities. Third, the establishment of closer relations between the universities of North and South America and between investigators in various fields.

An article by Señor Augusto Vicuna of Chile, Pro-Secretary of the Committee on Organization of the Pan-American Scientific Congress is published in the August number of *Revista de Devecho, Historia y Letras,* of Buenos Aires, and is translated in the October number of the Bulletin of the International Bureau of the American Republics. It is interesting as showing the attitude of a representative citizen toward this country. He says in part:

> The Pan-American Scientific Congress will have its part in cementing, upon the basis of mutual understanding and intellectual community, friendship with the United States—a country that for some time has drawn toward the young American Republics, not to satisfy ambitions for territorial annexation, but to offer them its aid in successfully fulfilling the duty of progress laid upon every nation aspiring to hold a place in civilization. The coming congress should give a mortal wound to the prejudices and false ideas that have kept us for nearly a century subject to an intellectual slavery in which Europe has dominated, and influenced us with its laws, customs, history and literature. While we appre-

ciate and esteem the intellectual aid which Europe proffers us, we wish, at the same time, to take an inventory of what we are receiving, in order to choose what does and refuse what does not accord with our social organizations, our customs, our traditions, and our education, which finally is the regulator of progressive capacity. It is necessary for America to develop its institutions in the light of its history, and the peculiar conditions of its social state.

To form an American mentality, to carry to the laws and to the national organism its own breath of life, to trace in the special peculiarities of each people that which is best for its moral, intellectual and material perfectionment—here is the beneficent idea which it is proposed to make central at the coming Congress. Everything tends to clear the road in order that the intelligence of the three Americas may join forces to bring to the solution of their problems a criticism, cool, independent, and free from the imposition of a foreign medium.

The once absolute supremacy of European ideas and criticisms was explicable. The enmities and jealousies which kept the people of the North and South apart—want of communication, difficulty of intellectual commerce (the precursor of material commerce)—worked so effectively that Europe was for nearly a century the school mistress who gave us her primers on political organization, her tracts on political economy, her texts on pedagogy; our speakers in enlightening public opinion leaned upon the authority of Bluntschill, John Stuart Mill, Adam Smith and others. Today all is changed. Powerful currents of cordiality circulate through the American organism. Thinking men from the Southern half of the Continent draw together, with men of the Northern half, inspired by a sincere purpose to study together the questions which concern the common country, America.

The creation of an American mentality forms a menace to no one, nor is it a formula to bring into being political alliances formed for aggressive purposes.

The Fourth Scientific Congress, The First Pan-American, will cement upon granite bases the union of the Americas, not to flaunt the sinister trappings of armed peace, but to give an example to the world of the subjection of prejudice and enmity to the cause of human progress.

PERSONALS

Mr. Francis W. Scarborough has opened an office under the corporate name of Scarborough & Howell, Inc., Richmond, Va., for the practice of architecture and engineering.

Prof. Edward Robinson of the University of Vermont, has obtained a year's leave of absence from the University. During this time he will visit the different universities in this country and abroad to note what they are doing along mechanical engineering lines.

Mr. Frank G. Bolles, formerly with the International Specialties Co., is now connected with Tungstolier Co., New York.

Mr. James H. MacLauchlin is no longer connected with the Cement Engineering & Construction Co., Saugerties, N. Y. He has accepted a position as Engineer with the American Cement Engineering Co. of 315 Fifth Avenue, New York.

Mr. William L. Caniff, who was connected with the United Engineering and Contracting Co., of New York, as master mechanic, has accepted a position with the T. A. Gillespie Co., High Falls, N. Y., in the same capacity on the Rondout Siphon tunnel.

Mr. Burdett Loomis, Jr., former president of the Loring B. Hall Co., Marlboro, Mass., is at present sales manager of Power & Mining Machinery Co. of New York, with offices in the Connecticut Mutual Building, Hartford, Conn.

Prof. C. C. Major, formerly assistant professor of engineering drawing of Ohio State University, has been appointed associate professor of mechanical engineering at the Iowa State College, Ames, Ia.

Mr. W. P. Dallett has been placed in charge of the branch of the Riverside Engine Co. which has just been organized and located at 49 N. 7th St., Philadelphia, Pa.

The corporate name of the Dodge Coal Storage Co. has been changed to, The J. M. Dodge Co. James M. Dodge, Chairman of the Link-Belt Co., is president.

Mr. George A. Buvinger, formerly connected with the Dayton Hydraulic Machinery Co., Dayton, as Chief Draftsman, is at present Hydraulic Engineer with the D'Olier Engineering Co., 119–121 So. Eleventh St., Philadelphia.

Mr. I. Woldenberg has left for Budapest, Austria-Hungary, where he is to represent the Ingersoll-Rand Co. He has been Chief Draftsman for this Company in New York.

Mr. Ernest L. Ohle has resigned his position as professor of steam engineering and head of the department of mechanical engineering at the State University of Iowa, to accept the position of professor of mechanical engineering at Washington University.

Mr. Horatio S. McDewell, who was assistant in experimental and engineering thermodynamics at Harvard University, is now with the Allis-Chalmers Co., West Allis, Wis. He was granted the degree of Master in Mechanical Engineering by Harvard University last June.

Mr. Carleton A. Read, formerly professor of mechanical engineering at New Hampshire College, has accepted the position of professor of steam engineering at Worcester Polytechnic Institute.

Mr. John R. Morgan, recently with the Morgan Engineering Co. in the capacity of mechanical engineer, is general manager of the Calumet Engineering Works Harvey, Ill.

Mr. J. Henry Sirich, Jr., recent turbine engineer with the Westinghouse Machine Co., has been engaged by the Bethlehem Steel Co. in the power department.

Mr. Charles S. Hamner, formerly located at 50 Church St., is now a member of the firm of Hamner & Moody, with offices at 25 Broad St., New York.

Mr. Edward W. Lindquist, Chief Draftsman Mining Department of the Allis-Chalmers Co., Milwaukee, Wis. has been transferred to the San Francisco, Cal., branch of that company.

Prof. W. A. Richards, recently connected with the University of Pennsylvania as teacher of hydraulics and materials testing, is with the University High School, connected with the Chicago University, and has charge of the foundry and forge departments.

Prof. Robert C. H. Heck, formerly professor of experimental engineering at Lehigh University, Bethlehem, Pa., has been elected by the board of trustees of Rutgers College, New Brunswick, N. J., to take charge of the recently established department of mechanical engineering. Civil engineering has been a department of Rutgers for many years, and the development of the engineering school has been marked by the establishment of a department of electrical engineering, by the erection of a new engineering building, now almost completed, in which the three engineering departments will be located, and by the installation, this year, of the department of mechanical engineering under Professor Heck's direction.

The Society learns with deep regret of the death of Mr. Bennett H. Brough, Secretary of The Iron and Steel Institute (London, England) which occurred at Newcastle-on-Tyne, Saturday, October 3. The funeral was held at the family residence, Subitor Hill, on Friday, October 9, at noon.

Prof. H. Wade Hibbard, professor of mechanical engineering of railways, Sibley College, Cornell University, has been selected by the board of curators to the chair of mechanical engineering in the University of Missouri. Professor Hibbard succeeds Prof. A. M. Greene, Jr., also a member of the Society, who resigned to accept a similar position at Rensselaer Polytechnic Institute.

Professor Charles H. Benjamin, member of the Society, recently appointed Dean of Purdue University to succeed Dean Goss, received from the Case School of Applied Science the honorary degree of Doctor of Engineering at their Commencement last June. Dr. Benjamin was professor of mechanical engineering at Case School before accepting the appointment at Purdue.

The degree of Doctor of Science was conferred by Stevens Institute of Technology upon Dr. Henry Smith Pritchett, President of the Carnegie Foundation for the Advancement of Teaching, at the last Commencement.

Dartmouth College conferred on C. J. H. Woodbury, at its last Commencement, the degree of Doctor of Science, this being the second time that he has received the same degree. The first was from Union College, New York, in 1906.

Francis W. Hoadley, for many years assistant to the Secretary of this Society, has recently been elected secretary and treasurer of the Cassier Magazine Co., New York.

Mr. F. E. Kirby, member of the Society, received at the last commencement the first degree of Doctor of Engineering conferred by the University of Michigan.

NECROLOGY

FRANK B. KLEINHANS

Frank B. Kleinhans was born at Easton, Pa., August 20, 1874, and died in Pittsburg, Pa., September 1, 1908. He was educated in the high school of Easton, and at Lafayette College, graduating in 1897 with the degree of Electrical Engineer. In 1900 he was given the degree of Master of Science. In 1897 he entered the employ of the Baldwin Locomotive Works, Philadelphia, where he remained for three years. In 1900 he entered the employ of Bement, Niles and Company, Philadelphia, as designer; in 1902 he became Chief Draftsman of Lodge & Shipley Machine Tool Company, Cincinnati, resigning the position in 1903 to become Chief Engineer of the Fischer Foundry and Machine Company of Pittsburg; he left this company in 1906 for the United Engineering Company, with which firm he was connected until his death.

He wrote extensively for the technical journals and was the author of a book on Boiler Construction. At the time of his death, he was writing a series of articles for The Boiler Maker on the subject of Flanging Boiler Plates.

He was a member of St. John's Lodge, No. 219, Free and Accepted Masons, Pittsburg, Pa.

FRANCIS X. McGOWAN

Francis X. McGowan, whose death resulted from a railroad accident on September 4, 1908, was born in Lawrence, Mass., February 11, 1877. He attended the public schools of that city, graduating from the high school in 1895, after which he entered the Massachusetts Institute of Technology, graduating from the mechanical course with the class of 1900. After graduation he entered the power division of the Western Electric Company, New York, and was later transferred to the engineering sales department. He remained in the employ of this firm to the time of his death.

Mr. McGowan was a member of the National Geographical Society and became a Junior member of this Society in 1902.

HARRY FRANKLIN GLENN

Harry Franklin Glenn was born at Holmesburg, Philadelphia, Pa., in 1848 and was educated in the Central High School of Philadelphia. For some years he was employed in the dry goods business in that city. In 1870, he went to Berwick, Pa., where he entered the employ of the Jackson & Woodin Manufacturing Company, car builders, holding successively the positions of Clerk, Superintendent of Rolling Mill, Treasurer, Secretary, General Superintendent and General Manager. Upon the formation of the American Car and Foundry Company in 1899, he became Assistant District Manager of the Berwick Plant and was later made Consulting Engineer of the Eastern Division of the same company. He was the oldest official in point of service at this industrial plant, having served thirty-eight years.

Mr. Glenn became a member of this Society in 1894. He died at Berwick, Pa., September 11, 1908.

WILLIAM HOLLOWAY BAILEY

Mr. William Holloway Bailey died October 4, 1908, at his residence, No. 200 West 57th Street, New York, in his seventy-fifth year. He was born in Boston, Mass., May 26, 1834. He was the pioneer of the brass and copper tube industry in this country and had been connected with the American Tube Works of Boston for over fifty-eight years and for the past fifty years was the New York representative of that company. He was the oldest member of the first panel of the sheriff's jury for the County of New York, and was a member of the Union League Club for over forty years. Other organizations with which he was connected were the Engineers Club, Downtown Association, Society of Naval Architects and Marine Engineers, New York Yacht Club, Geographical Society, Metropolitan Museum of Art, Museum of Natural History and the Academy of Design.

EFFICIENCY TESTS OF MILLING MACHINES AND MILLING CUTTERS

By A. L. DeLeeuw, Cincinnati, O.
Member of the Society

The design of standard machine tools was for many years, and has been until quite recently, a matter of practical experience, judgment and intuition, and might as well have been called guesswork. Special tools of unusual magnitude were built on somewhat more scientific principles, and this, perhaps, simply because the required dimensions were quite out of the scope of the designer's experience. It was not quite so easy to show judgment about a 6 in. as a 1½ in. lead screw; and it would not have done at all to make the screw 12 in. just to make sure; though the instances are not at all rare when some machine part, screw or shaft, on some smaller machine was made double the required size, simply to be on the safe side.

2 This condition was not due to ignorance on the part of designers or inability to apply engineering data, but to the fact that such data did not exist or were not public property when they did exist. Further, there was no inducement for the machine tool builder to spend time and money collecting data, as the tools, as built, filled all requirements to a reasonable extent.

3 This condition ceased to be satisfactory with the coming of the electric motor into the field of the machine tool builders. At first the wildest and most varied guesses were made as to the size of motor required to drive a certain tool. One builder would supply his machine with a 2½ h.p. motor, while another would equip the same size and style of machine with a 15 h.p. motor. This chaos was made worse by the fact that most purchasers of motor-driven tools

To be presented at the New York Meeting (December 1908) of The American Society of Mechanical Engineers.

The professional papers contained in The Journal are published prior to the meetings at which they are to be presented, in order to afford members an opportunity to prepare any discussion which they may wish to present. They are issued to the members in confidence, and with the understanding that they are not to be published even in abstract, until after they have been presented at as meeting. All papers are subject to revision.

The Society as a body is not responsible for the statements of facts or opinion advanced in papers or discussions. C55.

would specify the size of motor to drive the machine. One user would condemn the machine tool builder because the 10 h.p. motor was entirely too small and the next one because a 5 h.p. motor was much too large, for the same machine.

4 This brought before the machine tool builder the fact that a machine was not always used to its full capacity and was sometimes badly overloaded. In sheer self-defense the machine builder was compelled to determine for himself the proper size motor to be put on his machine, and he began to make tests and collect data. Crude as most of these tests were, they laid the foundation for a reasonable method of machine tool design.

5 Before some semblance of order was created out of this chaos, a second disturbing factor made itself felt: high speed steel.

MEASURE OF MACHINE TOOL PERFORMANCE

6 The first attempt of the machine tool builders was to determine the proper size of motor for a given tool. The difficulty they met was to determine when a thing was proper. The substitution of a motor for a belt was not the simple matter it looked. For years past machine tool designers almost uniformly credited a double belt with a pulling power of 50 lb. per inch width. Tests showed that a belt would do twice and even three times as much, though this was bad practice as far as the belt itself was concerned. Another factor in the calculation of the horsepower was the speed of the belt; but what was the speed, when the cone had four or more steps and the countershaft two or more speeds? And even if the belt power could be calculated, was this the proper power for the machine? Would the machine stand all that the belt would stand? Or again, was the driving power all the machine would stand? In other words, was there a proper relation between Power and Rigidity?

7 This showed the necessity of establishing some standard which would be a measure for the performance of the machine, a basis for calculating the size of motor or other source of driving power, and a gage to which the different functional parts of the machine could be proportioned. At first the pressure at the tool point was taken for this standard. A lathe would be specified as able to develop and stand a pressure at the tool point of, say, 6000 lb.; a planer was to have a pull at the table of 20 000 lb., etc.

8 This might have been a good standard if it were possible to determine the pressure on an ordinary machine. Tests were made

to find the pressure required for various cuts, but these tests required a special arrangement of tool post and could not be taken without modifying the construction of the machine. Experiments showed marked differences in horse power required to produce a given pressure at the tool post for a given speed of the work; in other words, the efficiency of a machine of given type and size was by no means a constant. This was no surprise, of course, but had been overlooked in some unaccountable way. In fact, it is being overlooked even now, and the idea seems to be abroad that each type of machine has its constant, expressing the ratio between energy delivered to the machine, and useful work done by it.

9 The difficulty of determining the pressure at the tool post required for a given cut led to the fairly general adoption of another standard, the amount of metal removed per minute. The whole matter is still in an unsettled condition. Specifications for machine tools calling for a guaranteed output are by no means general, but the general tendency seems to be in this direction. It is customary nowadays to call the buyer's attention to the size of driving pulley and width of belt and to the gear ratio, rather than to the output of the machine. This is misleading. Even if actual belt power—that is, the product of belt width and belt speed—were given, instead of size of belt, this would not indicate the capacity of the machine for removing metal; while gear ratio has absolutely no significance except to indicate the reduction in speed which one can obtain in a certain machine. It may be possible that some day in the future, machine tool builders will adopt a set of rules by which to indicate the capacity of a machine, and the first item would doubtless be the amount of metal removed per minute.

10 Though numerous tests have been made as to performance of machine tools, they have been confined almost exclusively to lathes. All other machines seem to have been considered as following the lathe in cutting characteristics.

SPECIFICATIONS OF MILLING MACHINE TESTS

11 When The Cincinnati Milling Machine Company intrusted me with the design of their line of Horizontal and Vertical High Power Millers, I found available a great mass of valuable data collected during the existence of this firm, but in order to start with a clean slate and unhampered by past experiences, I disregarded for the time being all these as well as all other data within my reach.

12 The main points to be settled were:

a How much metal shall a machine of given size be capable of removing?

b How much power is required for this work on existing machines?

c Is it possible to improve on the efficiency of present machines and still produce a commercially successful machine?

d How much power is required for the feed?

e What is the efficiency of the feed mechanism?

13 The first question was a point to be decided by the sales manager rather than by the engineer, as it was greatly a matter of competition. As is quite usual in the design of a new line of machines, the desired capacity was placed somewhat higher than that of other makes of similar machines. The customary method is to increase the size of driving pulleys or belt, or the gear ratio, or any combination of these elements. This was not deemed advisable, for two reasons. In the first place, nothing was to prevent competitors from going still further in this matter and so securing a seeming advantage in the sale of their machines without sacrificing anything but a few pounds of cast iron. In the second place, the purchaser of the machine is not interested in the amount of power which he can feed into the machine, but rather in the power of the spindle end, which to him is the business end of the machine. There can be no doubt but that it is better for the user of the machine if he can take a given cut with less belt or motor power. Not only does he save in power, but this power saved is power which would otherwise have been used to wear or destroy the machine.

14 To determine how much power was required to remove a given amount of metal, tests were made on various makes of machines. The metal to be cut was in all cases, both in these tests and in those to be described later, steel of the following specifications:

Combined carbon	.16 per cent
Silicon	.008 per cent
Manganese	.51 per cent
Phosphorus	.086 per cent
Sulphur	.041 per cent

Tensile strength per square inch	52378 lb.
Limit of elasticity	30313
Elongation per cent of length	50 per cent
Per cent reduction of area	54 per cent

15 The test blocks used were 18 in. long, 5½ in. wide and 5½ in. thick. The ends were milled in to provide means for holding the block on the table of the milling machine. In all tests a spiral cutter with nicked teeth was used, 3½ in. in diameter, 6 in. face, and for a 1½ in. arbor. The cutter was driven by a key, and made of high speed steel by The Union Twist Drill Company of Athol, Mass. All tests were made by driving the machine by an electric motor, belted to the machine. The object was to have all conditions as near as possible to those under which the majority of milling machines have to run, the only difference being that the belt was nearly horizontal instead of vertical. In testing the efficiency of machines in this way the belt must be considered part of the machine. The power consumed was ascertained by reading of ammeter and voltmeter, and the amount of metal removed by measuring width and depth of cut and the amount of feed per minute. The amount of feed, as indicated on the index plate of a milling machine, is generally an approximation, near enough for every day work but not for a test. The actual amount of feed was therefore computed from the gearing. In case the feed is a function of the spindle speed, that is, if the feed is expressed in thousandths of an inch per revolution, the feed per minute depends on the number of revolutions per minute of the spindle as well as on the amount of feed per revolution. The exact number of revolutions of the spindle at normal motor speed was determined by computing the gear ratio and pulley ratio. As pulley diameter the diameter of the pulley plus thickness of belt was taken. This computation would give the spindle speed at rated motor speed and without belt slippage. For this reason the speed of the first driving shaft of the machine was determined by the tachometer at each test. All readings were taken simultaneously. The number of revolutions of spindle and the feed per minute were corrected according to the tachometer reading.

16 Where the feed of the machine was independent of the spindle speed, that is, taken off a constant speed shaft, and therefore expressed in inches per minute, the same correction was made, as the amount of feed and therefore the amount of metal removed; here again was a function of the speed of the first driving shaft.

17 These preliminary tests showed considerable differences in the efficiency of different makes of machines, that is, one machine would cut considerably more material than another for a given amount of horsepower developed by the motor. They also showed that the efficiency of all machines was relatively low as compared

to the lathe. This latter might have been expected considering the nature of the cutting tool. As the main problem in a machine shop is not to save power, but to get the greatest possible output, this lack of efficiency cannot be held up against the milling machine as a type, for its other peculiarities make it highly efficient as a producer of work. The fact that one make is so much more efficient than another is of great importance, however. It shows that the less efficient machines:

a Use a needlessly large amount of power.
b Have less capacity than they might have for removing metal.
c Use a large amount of power constantly for the purpose of breaking down the machine.

18 It follows that it should be the aim of the designer to produce a machine of the highest possible efficiency as a power transmitter, because

a This increases the capacity of the machine.
b It insures long life and freedom from repairs.
c It is economical in the use of power.

19 This high efficiency requirement stands by itself. It must be supplemented, however, by other good features, such as convenience, etc. This paper deals with the efficiency problem only, and that only so far as to show results obtained, rather than the means by which they were obtained. It may be stated, however, that the main features aimed at, and considered essential to high efficiency, were the following:

a Absence of combined torsional and bending stresses in shafts.
b Absence of torsional stresses in shafts subjected to heavy loads.
c Moderate gear speeds.
d Moderate shaft speeds.
e Minimum number of gears in action.
f No gears rotating, which are not required for the transmission.
g Tumbler bearing anchored solidly, and not merely hung from a lever.
h Pulley shaft relieved of belt pull.

There was nothing radical or revolutionary in these points, but it was thought that strict adherence to well known principles should give the best obtainable results.

20 More complete tests were made after the line of High Power Millers was developed and completed. These tests were of three kinds:

a Tests determining the amount of metal removed per horsepower.

b Tests determining the efficiency of the feed mechanism.

c Tests determining the efficiency of the driving mechanism.

21 Three makes of machines were used, the new style Cincinnati High Power Miller, and two other makes, which for obvious reasons cannot be named here, and will be indicated by B and C. The sizes compared were the B No. 4 Plain, C No. 3 Plain, and Cincinnati No. 3 and No. 4 Plain, which will hereafter be indicated by the symbols 3-A and 4-A.

POWER REQUIRED TO REMOVE METAL

22 The same motor and belt were used for all cutting tests. A series of tests was made with a depth of cut of $\frac{1}{16}$ in.: then with a depth of $\frac{1}{8}$ in.; then $\frac{3}{16}$ in., $\frac{1}{4}$ in. and $\frac{3}{8}$ in. This complete test was repeated four times. The cutter was sharpened in the ordinary way before starting a complete series of tests, and not resharpened during test. The same cutter, resharpened, was then used for the next machine.

23 For each depth of cut a number of different feeds were used. In all cases the even feeds were used starting with the second (next to the lowest) and increasing thus: 2d, 4th, 6th, 8th, 10th, etc., up to the highest feed. It was of course impossible to go through the entire series with the deeper cuts, as the belt would slip before the last feed was reached. This slippage of the belt was at all times the end of the test for that depth, except where the entire scale of feeds could be used. Readings were taken, when the belt slipped, but these readings were not used in plotting curves. They served as a check on the belt tension. It was found that the ammeter readings gradually increased from the first to the fourth series. This was probably due to the gradual dulling of the cutter.

24 In plotting the curves, the test readings were first corrected: the power readings by means of the efficiency chart of the motor; the amount of metal for loss of speed of the machine. The curve as plotted is the curve of the average value of powers. Where the

curve shows an amount of metal removed of say $5\frac{1}{2}$ cu. in. per minute this amount may be due to a depth of cut of $\frac{1}{16}$ in. and a feed of 16 in. or to depth of cut of $\frac{1}{8}$ in. and a feed of 8 in., or perhaps a depth of cut of $\frac{1}{4}$ in. and a feed of 4 in.

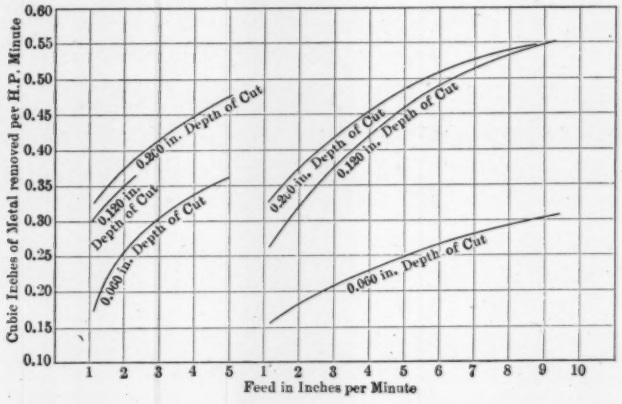

FIG. 1 CUTTING SPEED 12 FT. PER MINUTE

FIG. 2 CUTTING SPEED 32 FT. PER MINUTE

WORK OF 1 H.P. MIN. MEASURED IN CUBIC INCHES OF METAL REMOVED, FEED INCREASING

25 The amount of power required to remove a given amount of metal varied with the speed, depth of cut and feed per minute, and seems to have a tendency to the minimum when the section of the

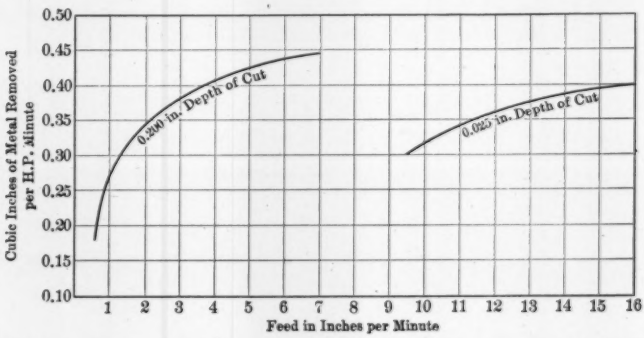

FIG 3. WORK OF 1 H.P. MIN. MEASURED IN CUBIC INCHES OF METAL REMOVED, CUTTING SPEED 45 FT. PER MINUTE, FEED INCREASING

chip removed per tooth approaches most nearly a perfect square. Fig. 1, 2, 3, 4, 5, and 6 show curves giving relation between power required and metal removed under different conditions of speed,

feed and depth of cut. They are partly derived from the tests described, and partly from tests made for the special purpose of ascertaining these relations. The fact that the power required changes

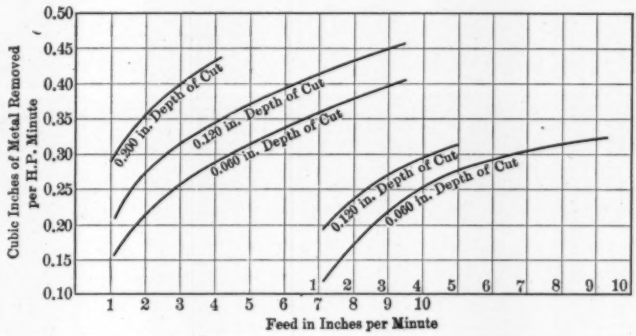

FIG. 4 CUTTING SPEED 67 FT. PER MINUTE

FIG. 5 CUTTING SPEED 150 FT. PER MINUTE

WORK OF 1 H.P. MIN. MEASURED IN CUBIC INCHES OF METAL REMOVED, FEED INCREASING

with these conditions of feed, speed and depth of cut made it impossible to plot a single curve giving relation between power and metal removed. Besides, the same speeds and feeds obtainable on one

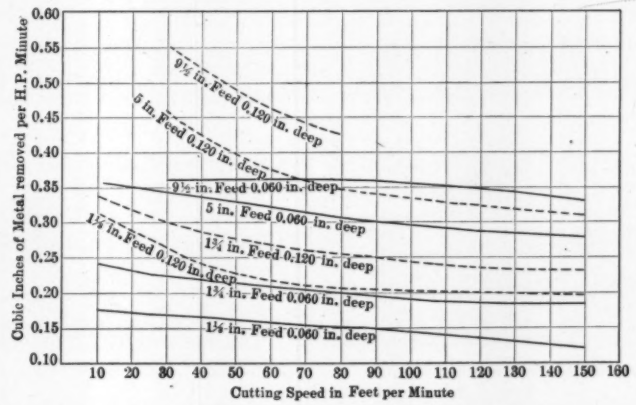
Cubic Inches of Metal removed per H.P. Minute
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
9½ in. Feed 0.120 in. deep
5 in. Feed 0.120 in. deep
9½ in. Feed 0.060 in. deep
5 in. Feed 0.060 in. deep
1¾ in. Feed 0.120 in. deep
1¼ in. Feed 0.120 in. deep
1¾ in. Feed 0.060 in. deep
1¼ in. Feed 0.060 in. deep
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
Cutting Speed in Feet per Minute

FIG. 6 WORK OF 1 H.P. MINUTE MEASURED IN CUBIC INCHES OF METAL REMOVED, CUTTING SPEED INCREASING

machine were not obtainable on another. And again, the amount of slippage or slowing down of the machine was not always the same for the same amount of metal removed. For this reason the averages have been

plotted, and these averages were obtained for the various machines in substantially the same manner. The curves were extended to the zero point, but the high point of all curves is the actual highest average obtained, so that in a certain sense the curves also show the comparison of the greatest possible capacity of these machines. This should be taken as significant, however, only when remembering the conditions under which the machines were tested, and then only as a measure for the maximum driving power.

26 No part of the A machines showed undue stress during the test. The B machine was strained in feed and drive parts, but showed sufficient rigidity in its other parts, while the C machine

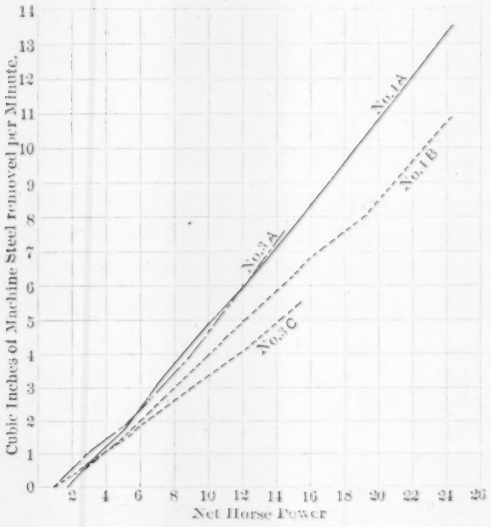

FIG. 7 CUTTING EFFICIENCY CURVES

was apparently in distress. It is only fair to say that all three machines were worked up to a limit far beyond what they would be called upon to do in daily operation. It goes to show, however, how utterly foolish it would be to furnish these machines with larger pulleys or wider belts for the purpose of giving them more capacity, as they can do much more work, even with their present pulleys and belts, than some of the other parts will permit. Multiplying the product of belt width and speed and calling this 100 for the 4-A machine, then the corresponding product for B No. 4 is 144. Calling this same product 100 again for No. 3-A, the corresponding product

for the C No. 3 machine is 154. This shows clearly again the small value to the buyer of the size of driving pulley or belt power, and once more shows the necessity for machine tool builders to come to some mutual understanding as to what should be their selling guarantee in regard to power.

27 Fig. 7 shows the curves obtained, the abscissae being the numbers of horse power net and the ordinates the numbers of cubic inches of metal removed per minute.

POWER REQUIRED FOR FEED MECHANISM

28 Tests made by the Cincinnati Milling Machine Company, as well as by other concerns engaged in the manufacture of milling machines, had shown that a considerable amount of power is required for the feed drive of a column and knee type of machine. It was found that as much as 40 per cent of the total power applied might have to be used for the feed alone: and that this could amount to as much as $3\frac{1}{2}$ h.p. on a No. 4 machine. Inasmuch as I did not conduct any of these tests and do not know all of the conditions under which they were made, I do not feel that I can present the results. The main result, however, as far as I was concerned, was the fact that they made me give very careful consideration to the feed mechanism. If $3\frac{1}{2}$ h.p. is used for the feed, and if that feed is 20 in. per minute (the highest feed found on a modern milling machine) then the pressure against the cutter must be

$$\frac{3\frac{1}{2} \times 33000 \times 12}{20} = 69\,300 \text{ lb.}$$

if there are no losses in transmission. Further, it is not likely that the greatest amount of horse power is required for the feed at its maximum number of inches per minute. It is more probable that the maximum of feed power is used for 10 in. feed or less per minute, in which case the pressure would be in the neighborhood of 140 000 lb.

29 A machine using 6 h.p. net for the drive alone (that is, using 6 h.p. at the cutter) would require about 8 h.p. at the pulley for the drive alone, and therefore a total of $11\frac{1}{2}$ h.p. for drive and feed under conditions of feed mentioned above. This is quite a respectable amount for a No. 4 machine. Assuming the cutting speed to be 40 ft., the pressure at the circumference of the cutter must be

$$\frac{6 \times 33\,000}{40} = 4950 \text{ lb.}$$

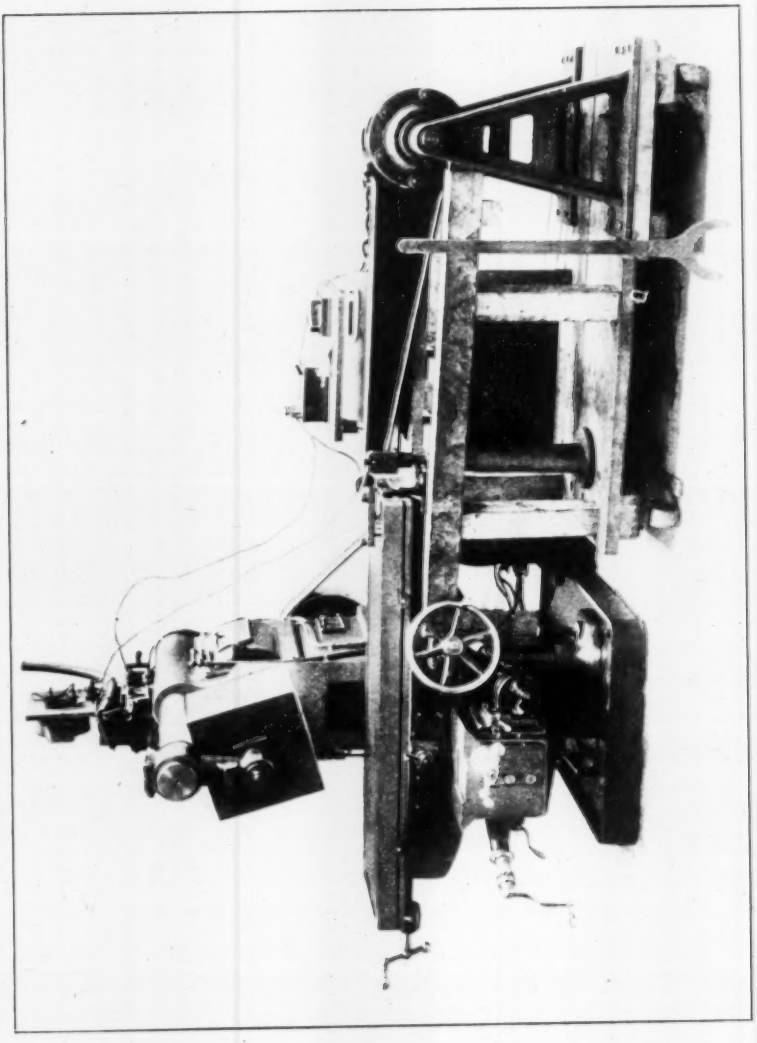

FIG. 8 APPARATUS FOR TESTING FEED EFFICIENCY OF MILLING MACHINE

and this must also be the approximate pressure against the table screw instead of 140 000 lb. Of course all these figures are assumed, but they illustrate the computations which led up to the second line of experiments to be described here.

30 In order to determine the efficiency of the feed mechanism, the amount of power used was measured, as well as the amount of work done by the table. As the amount of power required varied widely, and it would be impossible therefore to obtain an efficiency chart for some small motor, covering the entire range of powers used, the idea of using an individual motor for the feed alone was abandoned. Instead the same motor was used as had been used for other tests. The efficiency of this motor was not known below $\frac{1}{4}$ load. It was then necessary to provide an artificial and constant load for the motor. For this purpose the square box shown in Fig. 8 was mounted on the spindle arbor. It had a paddle inside and a number of obstructions which made the required resistance for the water in the box. By increasing the amount of water in the box, and by giving the paddle various speeds, any load could be produced within the range of the apparatus, and this load was constant. The box was kept from rotating by resting against the overarm of the machine. The dead load was adjusted until it came within the efficiency curve of the motor. The part of the apparatus used for measuring the work done by the table consisted of a dynamometer, graduated and calibrated up to 8000 lb.

31 One end of this dynamometer was attached to the table of the milling machine. A chain at the other end of the instrument was wrapped around a drum which was mounted on a brake of the Weston type. An arm, mounted on the brake casing and visible in the drawing had at one time been used to determine the efficiency of the driving mechanism but was not used in this experiment, except to form an abutment for the brake. The brake itself was used only as a safety device, being set at sufficient pressure for the test, but not enough to wreck the machine. It had been intended originally to set the brake for a certain pressure and to have the table feed under this pressure for some length of time, but it was found that the brake was too jerky in its action. The mode of working was therefore changed and the test was carried out as follows: All even feeds were taken, beginning with the second lowest and going up to the highest. For each feed the following pressures were selected: 1000, 2000, 3000, 4500 and 6000 lb. The entire series was repeated once if nothing happened to spoil the test. If something happened

to disturb the proceedings, or if something had to be readjusted, then the entire result of the test was dropped and no curve was plotted until two complete series of tests were made without interruption. A sensitive ammeter reading $\frac{1}{10}$ amperes was used. The tachometer served again to take the speed of the first driving shaft, and all corrections were made as in the test previously described. With a given feed, an entire series of pressures was gone through, after which the amount of feed was changed for the new series, etc.

32 Before taking a series of readings, the feed mechanism was disconnected to get the reading of the dead load. Another reading

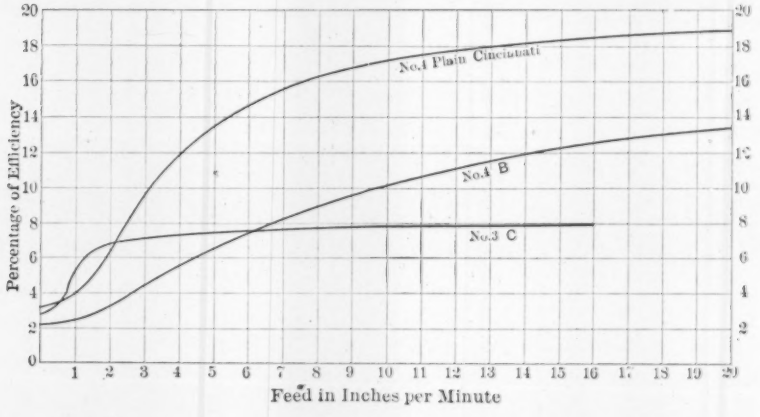

FIG. 9 FEED EFFICIENCY CURVES

of the dead load was taken after each series of readings was completed: that is, after all the different pressures had been used for one single feed. One observer took the readings of the tachometer; another of the ammeter; a third one of the dynamometer, and a fourth one was stationed at the feed starting lever. The observer of the dynamometer watched his instrument until the pointer reached the proper figure, when he would call out sharply. At this moment all readings were taken and the feed disconnected. Several preliminary tests were made to see if the readings could be duplicated in this fashion, and it was found to be very easy to do so. The rise in the ammeter readings was gradual, and allowed the observer to take the correct reading every time within a tenth of an ampere. If there

was any drop in the speed of the machine, this drop was also very gradual, permitting the tachometer readings to be easily duplicated. The only point not so easily duplicated was the reading of the dynamometer, especially at the faster feeds. It often happened that the feed pressure would go somewhat beyond the pressure intended, but the dynamometer did not change its position when the feed was thrown out, so that the observer could take his reading at leisure, the only difference being that instead of having to plot for say 2000 lb. the curve might have to take care of 2100 lb.

33 Fig. 9 shows the curves of average values plotted from these readings, in which each ordinate is the average of the ordinates corresponding to a certain amount of feed. The results of these tests justify again the precaution taken to obtain an efficient feed mechanism in the new line of milling machines. It may be mentioned here that these precautions consisted in avoiding idle running gears, high gear velocities, combined torsional and bending stresses in shafts, and ill supported and floating bearings, and above all, in the use of quick pitch screws.

34 The importance of a higher efficiency in the feed gearing cannot be over-estimated. It may seem that 20 per cent efficiency is still so low that it makes little difference whether it is this amount or something else. It may seem at a first glance that it is of little importance to the user whether 80 per cent or 90 per cent of the feed power is lost in transmission. But a more careful look at this problem shows the importance of high efficiency very clearly. If 3 h.p. out of 10 are used for feed on a machine of which the feed efficiency is 10 per cent, then 0.3 h.p. is actually used for this feed. If 10 h.p. is used for the entire machine—that is, for feed and drive—then 7 h.p. is left for the spindle drive alone, and therefore the amount used for feed is $\frac{3}{7}$ of the amount used for the spindle drive. With a machine having a feed efficiency of 20 per cent or twice as much, the amount of power used for the feed will be $\frac{3}{14}$ of the amount of power used for the spindle drive alone, or $\frac{3}{17}$ of the total amount used for the machine. If this amount is 10 h.p. again, then the amount used for the feed will be 1.76 h.p. as against 3 h.p. in the first machine; and the amount left for spindle drive will be 8.24 as against 7 h.p. in the first machine, giving an increased spindle power of 18 per cent available for cutting. Of the 3 h.p. used by the first machine for the feed alone, 0.3 h.p. is usefully employed while the remaining 2.7 h.p. are employed to wear down the feed mechanism and destroy the machine. Of the 1.76 h.p. used for feed in the second machine,

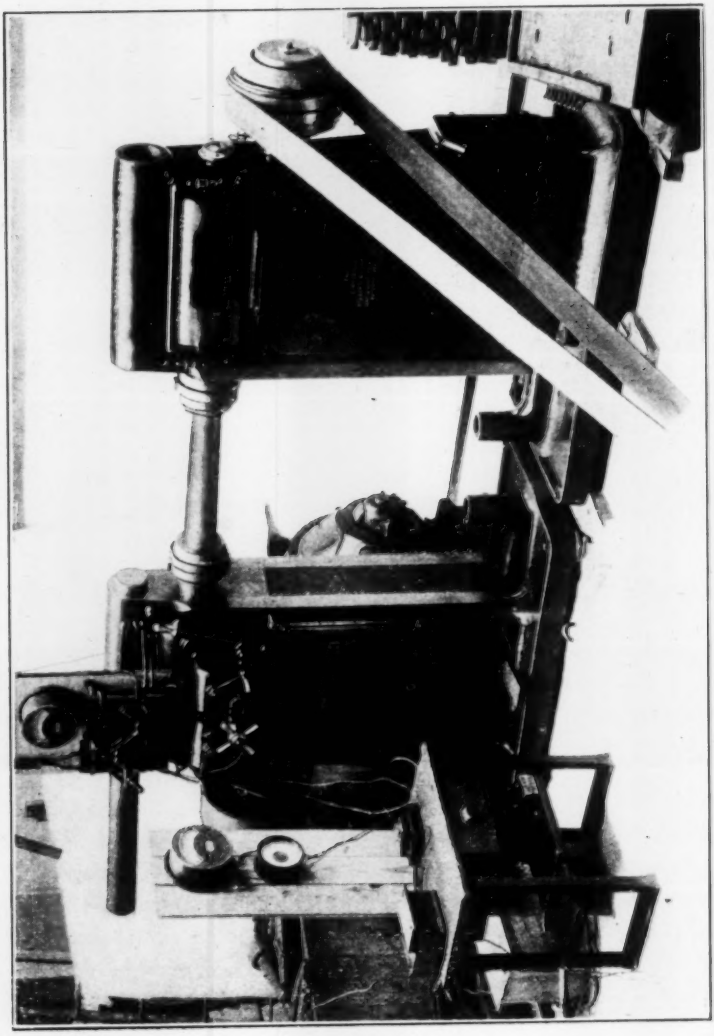

FIG. 10 APPARATUS FOR TESTING EFFICIENCY OF MILLING MACHINE DRIVES

20 per cent or 0.352 h.p. is usefully employed, whereas the remainder or 1.41 h.p. is used destructively. It will be seen therefore that the power used to break down the machine is almost twice as great in the first machine as it is in the second.

TESTS UPON EFFICIENCY OF DRIVING MECHANISM

35 The third series of tests relates to the efficiency of milling machines as power transmitting devices: that is, the ratio of input and output of power. Some preliminary tests were made by observing the power at the spindle by means of an absorption brake of the Weston type; in fact, the same brake as illustrated in Fig. 8. This gave fairly good results at the higher speeds, the torque being small; but at the lower speeds and with greater torque the action of the brake became jerky and it was practically impossible to obtain reliable readings. For this reason the tests were carried on with the apparatus shown in Fig. 10.

36 This consisted of two machines of the same type, make and size—namely, Cincinnati No. 4 High Power Miller—placed opposite each other and connected by a stout shaft. The feed works were removed, as were also knee, saddle and table, so that nothing was left but the bare frames and driving works. The machines were placed with the spindles approximately in line. A flange was screwed to the nose of each spindle; each flange was provided with a tongue engaging the groove in the similar flange opposing it, and keyed to the stout connecting shaft. There was plenty of clearance between tongue and groove and also endwise so that the connection could behave as a universal joint shaft in case the spindles were not exactly in line. It must be remarked here that the motion in this universal joint shaft was exceedingly small. Flat pieces of steel bolted to the first mentioned flange prevented the connection from coming apart. One of the machines was driven by a motor while the other drove a generator. The current thus generated was dissipated in a water rheostat, by means of which the amount of current could be closely regulated. There was a set of electric instruments for motor and generator each, so that all readings could be taken simultaneously. Both machines were driven by belts. A tachometer was used to determine if one of the belts slipped excessively. If the generator volt-meter showed considerable drop and the tachometer showed about the proper speed at the first driving shaft of the first machine (motor machine) then the belt to the generator must have slipped.

If however the tachometer showed a drop, then the belt from the motor to the first machine must have slipped.

37 The speed controlling levers of both machines were always in corresponding positions—that is, both were set for the same speed, so that at whatever speed the spindle was running, both driving pulleys were always running at the same speed, and that is the speed at which they are supposed to run under working conditions. Different sets of readings were taken. In one set the current consumed was kept at as near 125 amperes as possible. In another set this amount was 100 amperes; in still another, 80, and in the fourth, 70. Each set of tests was carried out over a number of speeds, namely, the lowest, third, fifth, etc., up to the highest but one. After correcting the motor reading for motor efficiency and generator reading for gen-

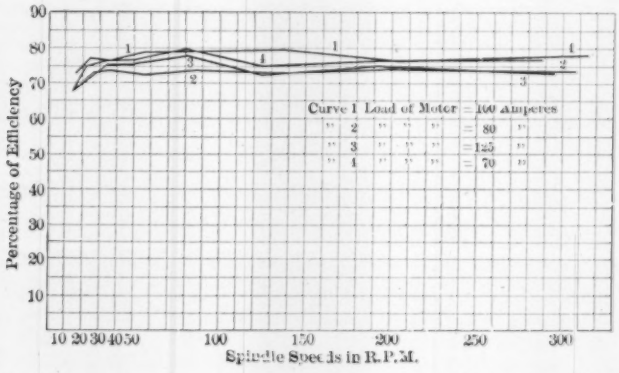

FIG. 11 EFFICIENCY CURVES OF NO. 4 CINCINNATI HIGH POWER MILLER.

erator efficiency, the quotient of the corrected readings gives the product of the efficiencies of the two machines.

38 It would be proper to consider the two machines as of equal efficiency if the conditions of load were the same, for these tests did not attempt to establish the efficiency of an individual machine but of a type of machines and this could best have been done by submitting a great number of these machines to individual efficiency tests and taking the average of the results. It is therefore plain that a better result will be obtained by considering at once the two machines as having the same efficiency than to attempt to determine their individual characteristics. It was said that it would be proper to do so if the conditions of load were the same for both machines, but this did not seem to be the case. The load was the same only at

the spindle noses. From there on and up to the driving pulley the load increased in the first and diminished in the second machine. The efficiency of the first machine is made up of the efficiencies of its bearings, shafts, sets of mating gears, etc. These efficiencies may be called $e1$, $e2$, $e3$, etc. The total efficiency of the first machine being E, then $E = e1 \times e2 \times e3$, etc. Similarly, taking F as the symbol of the efficiency of the second machine, then $F = f1 \times f2 \times f3$, etc. The f's may be assumed to differ from the e's on account of the difference in load.

39 It was found however on taking the readings that there was such a small difference in efficiency whatever the load, that it seems to be allowable to consider the efficiency as practically constant: in which case the efficiency of each machine equals the square root out of output divided by input. The curves presented in Fig. 11 are based on this assumption. It will be seen that the efficiency of the machine varies from 67 up to 79.7. Various tests made at other times have shown repeatedly efficiencies above those plotted in the curves, but it was not thought advisable to embody them in these curves as there were not enough readings to make a complete set and the use of these isolated readings would have a tendency to disturb the effect of the systematic tests.

EFFICIENCY OF CUTTERS OF DIFFERENT TYPES

40 The milling machine is not essentially less efficient as a power transmitter than any other machine tool, but the amount of metal removed per horse power per minute is low; much lower in fact than for the lathe or planer. Were it not for other properties the milling machine could not compete with either of these two machines. It is fortunate for the milling machine that the question of power consumption is of minor importance in considering the purchase of machine tools. Still it cannot be denied that the milling machine would be esteemed higher if its power consumption could be brought down to the level of the lathe. It is obvious that this cannot be done by increasing the efficiency of the mechanism as the margin is not large enough to allow of any material improvement. Any substantial increase of efficiency must therefore be found in improvements of the cutting tool. With this consideration in mind, some tests were made as to the power required to remove a given amount of metal with different styles of cutters. These tests have not been carried out over a long enough period or with a large enough

variety of cutters to give absolutely reliable results, yet, incomplete as they were, they bring out in a startling way the amount of improvement that may be made in this direction.

41 Cuts made with a spiral cutter with nicked teeth showed a best efficiency of 0.48 cu. in. of metal per net horse power per minute, and this efficiency was obtained only in a few isolated cuts and with a very sharp cutter. Cuts made with a 14 in. face cutter with inserted teeth and on a No. 4 Cincinnati High Power Miller showed a production of 0.64 cu. in. per net horse power per minute, an increase of 33⅓ per cent over the spiral cutter. This result confirms the gen-

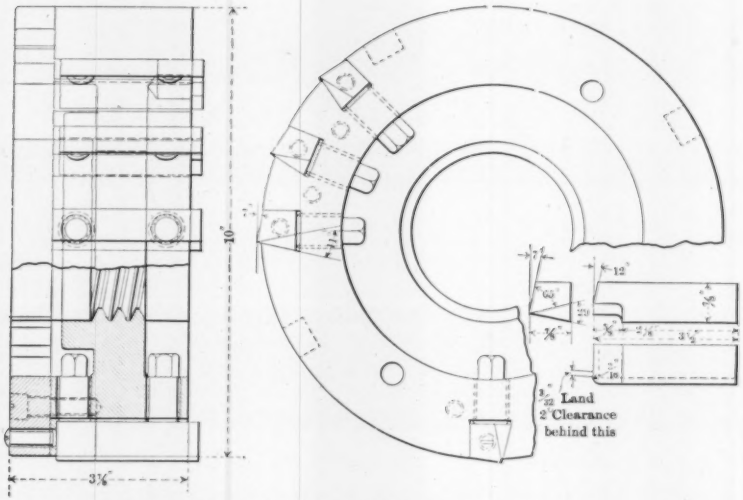

FIG. 12 10-IN. 16-BLADE CUTTER

eral belief that a face cutter cuts freer than a spiral cutter. The teeth of this face cutter were radial, as it is customary to make them. Tests made with the cutter shown in Fig. 11 showed an efficiency of 0.96 cu. in. of metal per net horse power per minute, and a few isolated cuts even higher. This is an improvement of 100 per cent over the spiral cutter and 50 per cent over the face cutter with radial teeth. The cutter shown in Fig. 12 showed the same efficiency. Both cutters have the blade set tangent to a circle concentric with the cutter, thus giving them a rake angle of 15 deg. The clearance was 7 deg. The points of the cutting blades were rounded to prevent injury by burning or chipping, and this reduced the effective rake

near the horizontal tangent to this curve. It was for this reason that the blades were set leaning backward as in Fig. 12. But for this curvature at the point of the blades, the simpler construction of Fig. 11 would be perfectly satisfactory. The leaning back of the blades is rather a refinement than a necessary improvement.

42 It should be borne in mind that the tests made with these cutters were made on a vertical machine which had the same driving parts as a horizontal machine of the same size, and besides an additional two shafts and four gears, so that it is safe to say that its mechanical efficiency must be less than that of the No. 4 horizontal machine used with the spiral cutter with nicked teeth. The action

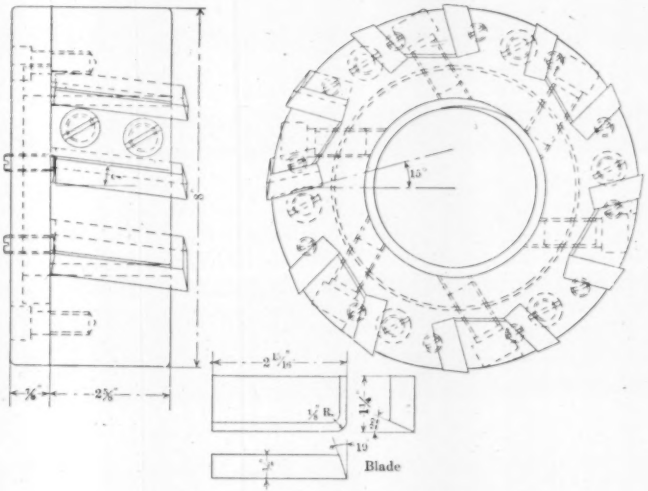

FIG. 13 8-IN. INSERTED TOOTH CUTTER

of the feed on a machine using this cutter may be somewhat different from that on a machine using spiral cutters. Whether there is such a difference and what it amounts to has not been ascertained by tests, and might be a promising field to explore. The fact that, generally speaking, the face cutter with rake removes double the amount of metal with the same amount of power as compared to the spiral mill is significant and places the vertical machine in the front rank for slabbing work wherever it is possible to use this type. Equally significant is the fact that a cutter with rake removes 50 per cent more metal than a cutter without rake. It may be mentioned here that many of these cutters, especially for so-called rotary planers,

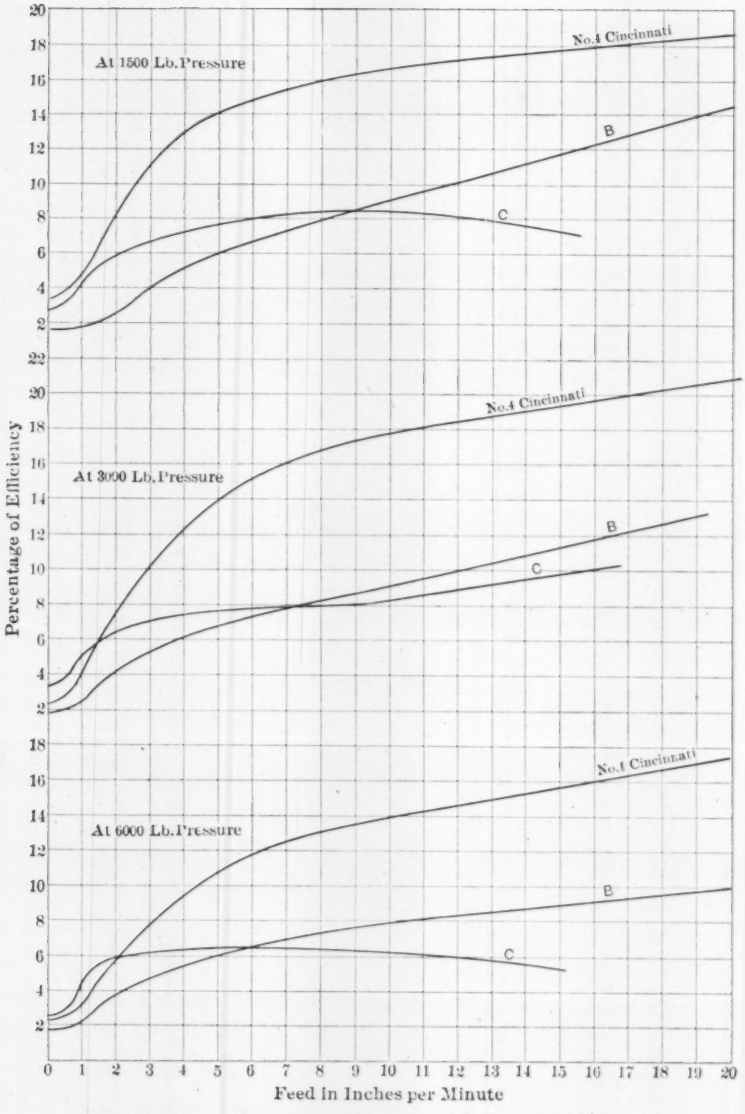

FIG. 14 FEED EFFICIENCY CURVES AT DIFFERENT PRESSURES

are being made and have been made for a great many years with the teeth leaning backward as in Fig. 12 but without rake; the makers and users apparently believing that this leaning constitutes rake.

43 I regret that the requirements of patent laws do not permit me at the present date to describe a spiral cutter and a face cutter built on different principles, which have been tested as to their efficiency. It may be of some interest however to know that a great number of cuts have been taken with these cutters showing removal of 1.14 cu. in. per net horse power per minute, and with entire absence of chattering of machine and spring of the cutter arbor.

44 The writer is fully aware of the fact that the tests described above are by no means complete, and he believes that they are only a starting point and that much more should be done in this line before we can say that we have sufficient working knowledge of the efficiency of drives and feeds of milling machines and of milling cutters. The fact that so little has been published on this subject has led him to submit this paper, incomplete as it may be.

INDUSTRIAL PHOTOGRAPHY

By S. Ashton Hand, Cleveland, O.
Member of the Society

Photographs of machinery, interiors of shops, products of machines, processes of manufacture, etc., are generally made to aid the selling department of an establishment in disposing of its product.

2 Sometimes the photographs themselves are used as an advertising medium, but in the majority of cases half-tones are made from them for use in catalogues, or for illustrations in trade journals. Catalogues have of late years developed into veritable works of art, and their preparation calls for photographic work of the highest order.

3 To this end it should be the aim of the photographer to produce prints that will require the least retouching when used for making half-tones, and this for two reasons: First, the retouching of prints for half-tone work is quite expensive; and second, the print that requires the least retouching gives much the best results in the finished half-tone. A print which requires very little retouching to produce a first class half-tone is a good one for all other purposes, but a print good enough for all other purposes may be a very poor one from which to produce a first class half-tone.[1]

4 Nearly all industrial establishments are equipped with a photographic outfit of some kind, and in some instances an experienced photographer is in charge; but in the majority of cases one of the draftsmen must take care of all the photographic work of

[1] The reproductions in this paper were made from photographs upon which there was no retouching whatever.

To be presented at the New York Meeting (December 1908) of The American Society of Mechanical Engineers.

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The Society as a body is not responsible for the statements of facts or opinions advanced in papers or discussions. C55.

the establishment, and it is in the hope of aiding some of the latter that this paper has been prepared.

APPARATUS

5 The camera should be a strong and serviceable one having a long bellows with very little cone. In fact, one with a perfectly straight bellows is best, as it allows greater adjustment of the lens board without danger of the bellows folds cutting off any of the object. The vertical and side swings should be ample.

6 The camera need not be larger than 6½ by 8½ in., and should not be larger than 8 by 10 in., as anything over this size is cumber-

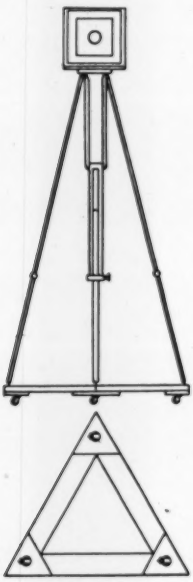

FIG. 1 TRIPOD WITH TRIANGULAR BASE

some to handle, and requires a very expensive lens and a great deal of skill to operate.

7 If large prints are wanted, bromide enlargements can be made up to any reasonable size, and if for any reason large direct or contact prints are wanted, a slightly enlarged positive can be made from the negative, and a negative as large as wanted can be made from the positive. This procedure has its advantages, as it is often possible to correct in a great measure any errors in exposure or development, and many errors in lighting and position.

8 The writer never uses a camera larger than 6½ by 8½ in., and has produced many excellent enlarged negatives up to 24 by 36 in., by the method above mentioned.

9 The tripod should be solid and stiff with the fewest possible joints. An excellent thing for use with it is a triangle with sides about 36 in. long, and with a roller or caster under each point as shown in Fig. 1. With the tripod mounted on this arrangement, the camera can be moved any distance or in any direction without material change in level.

10 The lens should be the best obtainable, and too great emphasis cannot be placed on its being of long focus. Never under any circumstances should its focus be shorter than the diagonal of the largest plate with which it is to be used. It should be capable of rendering sharp definition from corner to corner of the plate when using a comparatively large diaphragm. A lens of this character will render the focusing much easier, and will enable the exposure to be made in the shortest possible time.

11 The plates should not be the most rapid made, as the emulsion with which these are coated is not generally rich enough in silver to give printing density for anything but portrait work, and also because the timing of the exposure must be very exact. Unless both exposure and development are just right, the negative will not be "snappy" enough to produce a good bright print.

12 Very slow plates take long exposures, and unless skillfully handled in development will produce prints with entirely too much contrast. Plates of medium speed are the best and should be of the kind known as "double coated" or "non-halation." Plates of this kind are first coated with a slow emulsion, and after drying are again coated with a somewhat faster emulsion. Plates so coated allow of very great latitude in time of exposure.

13 If interior views are to be made where windows and other openings to the light have to be faced, then the plates should be coated on the back with a compound known as "backing." This will prevent to a great extent halation or blurring of the high lights caused by reflection of light from the surfaces of the plate under the emulsion. This "backing" should be washed off with a damp sponge before development.

PREPARATION OF THE SUBJECT

14 If a machine is to be photographed, it should be painted with a finishing coat of drab paint, which may be designated as "mouse

color," and the paint should be so mixed as to dry absolutely "flat," that is, without any gloss whatever. If parts underneath the machine or in shadow are wanted to be shown, they should be painted a lighter shade than the more prominent parts, and the deeper they are in shadow the lighter they should be painted, even in extreme cases blending the color gradually into a white. All brightly polished parts should be daubed or rubbed over with a handful of soft putty to dull the brightness.

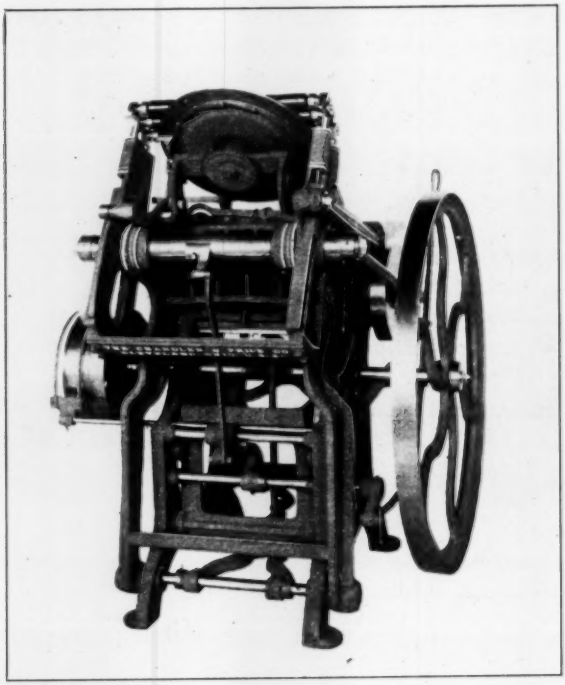

FIG. 2 DETAILS BROUGHT OUT AND SHADOWS AVOIDED BY PREPARATION OF MACHINE PARTS BEFORE PHOTOGRAPHING

15 Unless these precautions are taken, the parts in shadow will show very dark in the photograph, and if very close together will be seen only as one shapeless mass, and the bright spots will show chalky white with very black lines and little or no detail. If letters or figures cast on any part of the machine are wanted to be shown, daub them with white paint from the end of a finger. Rubbing with chalk will give them a very rough appearance.

16 It must be borne in mind that all high lights and shadows are greatly intensified in photography, and that a sensitive plate that will register all the gradation of tone as seen by the human eye has yet to be made.

17 Fig. 2 and 3 are illustrations of machines that were properly prepared for being photographed.

18 If possible, it is best to photograph a machine before it has been run, otherwise oil from the bearings will seep out on the paint

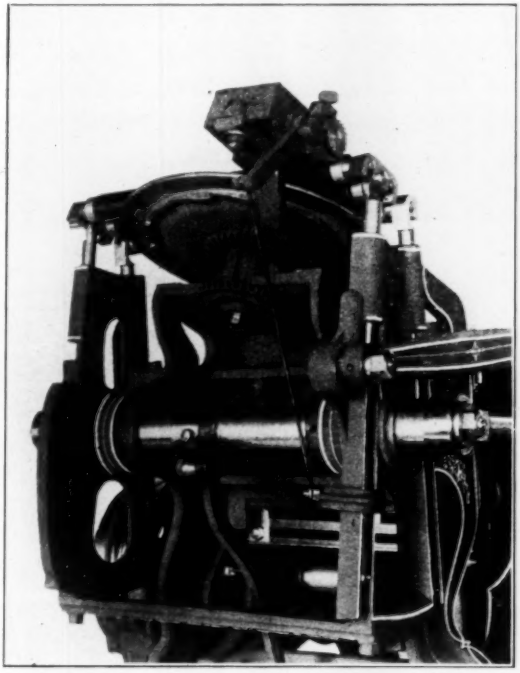

FIG. 3 DETAIL OF FIG. 2

and leave dark and glossy spots which will look badly in the photograph. If the machine is to be run before being photographed, then it should not have its finishing coat until after the run or test is over. Before the finishing coat is put on, all the bearings should be thoroughly flushed with gasolene and the whole exterior cleaned with the same stuff to remove all oil.

LIGHTING AND POSITION

19 Machinery should never be photographed out of doors or under a skylight, as there is too strong a top light which causes deep shadows.

20 The light should preferably come from the north, and should fall on the machine at a downward angle of about 20 deg. from the horizontal. Cross lights from other windows should be avoided by pulling down the shades or tacking up heavy paper. Cross lights make a confusion of shadows and obliterate certain lines, giving the machine anything but a natural appearance. If necessary to photograph the machine by other than northern lighting, then make the

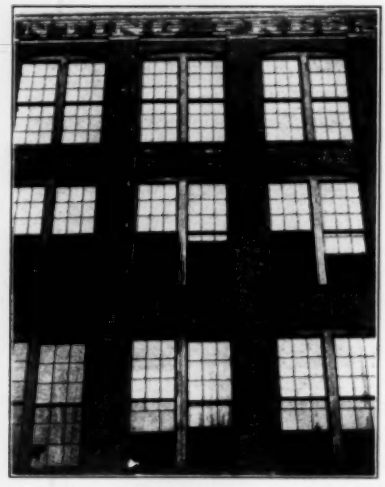

FIG. 4 DISTORTED VIEW MADE BY POINTING THE CAMERA UPWARD

exposure when the sun is overhead. If the exposure must be made when the sun is shining through the windows at any considerable slant, tack cheese cloth over the windows to diffuse the light.

21 A machine should never be photographed directly from the front, which will make it appear too flat. For depth, the camera should be placed enough out of center to show a little of one side of the machine and high enough to show a little of the top.

22 A background of heavy drilling, either white or very light in color, should be hung not less than 6 ft. back of the machine. It should be of ample size—large enough so that the camera can be

moved where wanted and still show the background behind every part of the machine. If there are folds or wrinkles in the background, have a man at each side take hold of the edges and shake the curtain slowly and gently during the whole time of the exposure. This will prevent the folds or wrinkles from showing in the photograph.

23 Shop floors are dark in color, and if a machine is photographed directly on the floor it is often puzzling to know where the lower part of the machine ends and the floor begins. Therefore a floor cloth of the same color and width as the background should be used. It should be deep enough to extend from 4 to 6 ft. in front of the

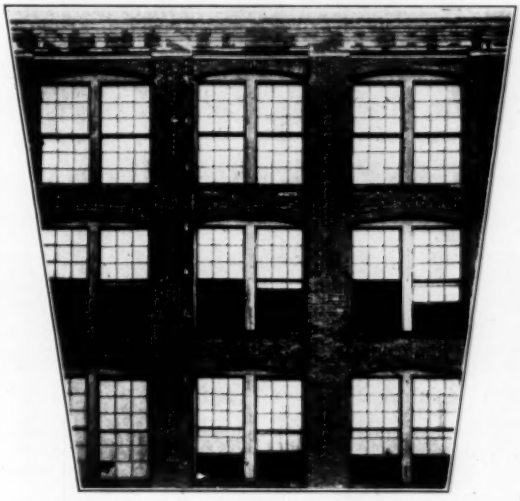

FIG. 5 DISTORTION OF FIG. 4 CORRECTED IN REPRODUCTION

machine and under it and to the background. This will define the lower parts of the machine, and also reflect the light upwards, softening the shadows. Instead of a floor cloth, sheets or strips of light colored paper can be used, but be sure there is no pronounced red or yellow, as such colors are non-actinic and will show black in the photograph.

FOCUSING

24 Never focus on the center of the ground glass, as this will give you the point of sharpest focus of the lens and what is wanted is the average focus; therefore focus at a position midway between the

center and the edges of the ground glass. Get the nearest parts of the machine in focus. Small diaphragms will sharpen up the distant parts.

25 Sometimes a better effect can be obtained by pointing the camera slightly downward, but if at any time the camera is used in any other than a level position, the ground glass should be brought to a vertical position, otherwise the result will be distorted lines.

26 Fig. 4 shows a distorted view of a part of the side of a building, made by pointing the camera upward. If the photograph of a

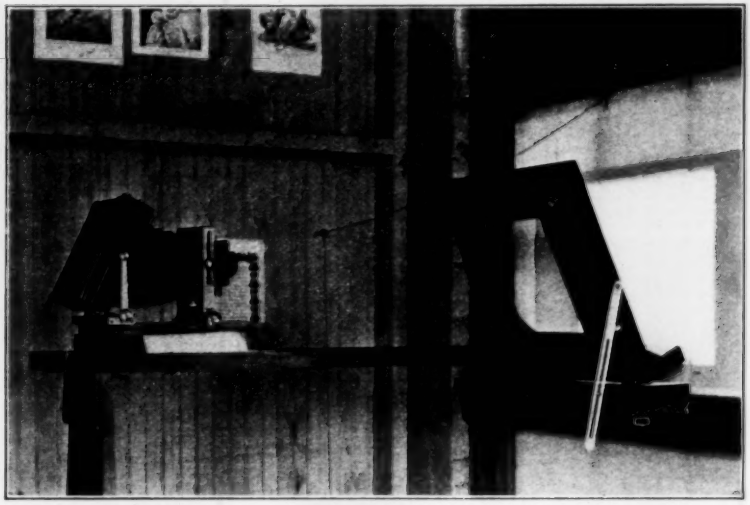

FIG. 6 CAMERA AND NEGATIVE HOLDER ARRANGED SO AS TO CORRECT DISTORTION SHOWN IN FIG. 4

machine shows such distortion, and for any reason it can not be photographed again, a negative can be reproduced eliminating the distortion, by placing the negative in a frame tilted at such an angle that the narrowest lines are nearest the lens, and making a positive in the camera, tilting the ground glass at an equal angle, but in the opposite direction. A negative can be made from this positive, as shown in Fig. 5, which was actually made from a negative reproduced in the above manner from that used for Fig. 4. Notice how much the top of the negative had to be enlarged to bring the lines parallel.

27 Fig. 6 shows a camera and negative holder in the proper position for this operation.

28 If the machine to be photographed is a long one, requiring a raking view, use the horizontal swing to bring that part of the ground glass on which the image of the farthest part of the machine appears, farthest away from the lens. This will even up the focus and make it possible to use a larger diaphragm, shortening the time of

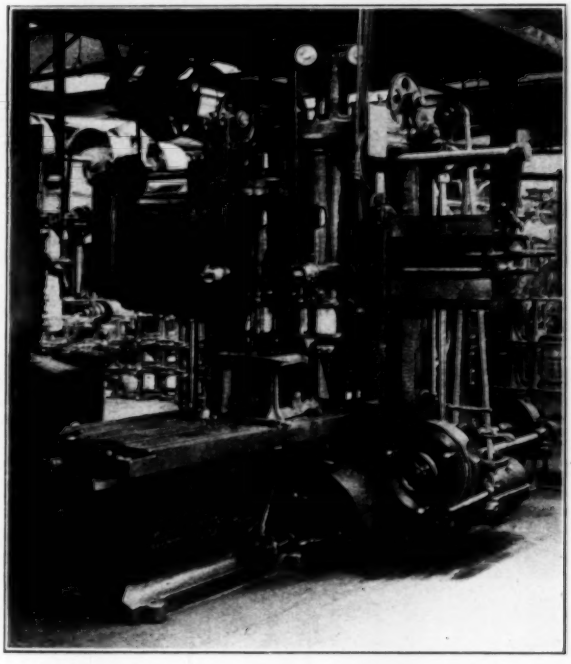

FIG. 7 DETAILS OF A DARK SHOP BROUGHT OUT BY LONG EXPOSURE

exposure, and also extend the vanishing point to a greater distance, giving it a more normal perspective.

29 If there are perceptible vibrations to the floor on which the photographing is done, get three pieces of harness felt $\frac{1}{2}$ in. thick, and two or three inches square. Place one of these on the floor under each leg of the tripod, and they will absorb all ordinary vibrations and keep the camera steady.

EXPOSURE

30 Exposures should always be ample, as an under-exposed plate can never be made to show that which the light has not impressed upon it (although it can be greatly helped by skillful development), but a moderately over-exposed plate can easily be treated in development, or even afterwards, so as to yield a first class print. Fig. 7 is an illustration of details brought out by long exposure in the dark part of a shop.

FIG. 8. PHOTOGRAPH FROM NEGATIVE TAKEN WITHOUT SPECIAL PRECAUTIONS AGAINST STRONG LIGHT—STRONGEST LIGHT AT FAR END.

31 If in doubt as to the correct time of exposure, make a guess as near as possible. Suppose your guess to be four minutes, then put a loaded plate holder in the camera and draw the slide so as to expose two inches of the plate and make an exposure of two minutes; cap the lens, draw the slide out two inches more, and make another exposure of two minutes. Repeat this, drawing the slide two inches at a time, until the whole plate has been exposed.

32 If the plate is an 8 by 10, there will be five parts having respective exposures of 10, 8, 6, 4, and 2 min. each. Develop this plate, and it will be easy to tell which part has had the proper exposure, and from the position of this part the time can readily be found.

INTERIORS

33 In photographing interiors, avoid pointing the camera towards windows if possible, but if this cannot be avoided, then cover the windows with heavy drilling or thick wrapping paper, fastening it

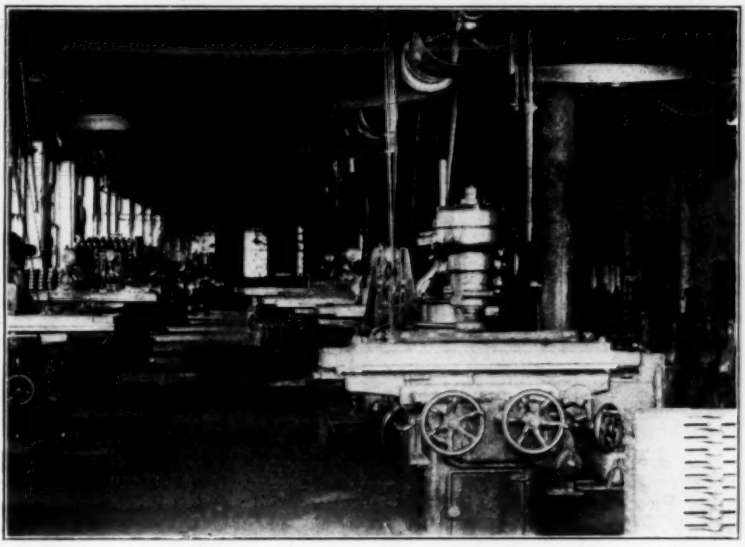

FIG. 9 SAME CONDITIONS AS IN FIG. 8, BUT WITH STRONG LIGHT IN FOREGROUND

well around the edges, so that no bright margins of light are visible. After the exposure has been made, the window coverings can be removed and an additional exposure of a fraction of a second can be given. This will give the windows a natural appearance and will often show objects on the outside. Interiors can be photographed without these precautions, but skillful work will be required to make good negatives.

34 Fig. 8 and 9 were made on a very bright day when snow was on the ground, and the light coming in the windows was intensely white. As the negatives were wanted in a hurry, no precautions

were taken to soften or stop out the light at the windows. The far end of Fig. 8 was a southern exposure, and the sunlight was streaming in at the windows. Fig. 9 is a view in the same room taken from the south end, where the light was so intense that the milling machine in the foreground appears light in color, although it was painted a dark steel color.

35 Fig. 10 shows work in process in a special machine. This was made on the same day as Fig. 8 and 9, and with the camera pointed directly at the light. To work successfully under such conditions, the photographer must know to a nicety just how long a

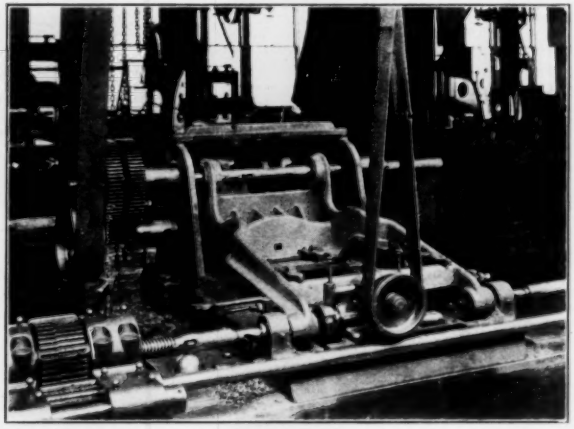

FIG. 10 PHOTOGRAPH ON SAME DAY AS IN FIG. 8 AND 9. CAMERA POINTED DIRECTLY TOWARDS THE LIGHT

certain kind of plate may be exposed before halation takes place, and just how to get the best results in development from the shortest permissible exposure.

COPYING

36 In copying drawings or other subjects in black and white, it is necessary to use a very slow plate, give the shortest possible exposure, and use a concentrated and well restrained developer. Unless this is done, the lines of the drawing will not be clear and sharp.

37 If a copy is to be made from a blue print, it will be necessary to bleach the print in a weak solution of ammonia and water, and

after a thorough washing, to immerse it in a weak solution of tannic acid. The part that was formerly blue will now be a rich purplish brown. The necessity for this treatment is that blue is an actinic color, and a negative made from such a print will have very little contrast; while brown is a non-actinic color, and a negative made from a print of that color will have plenty of contrast.

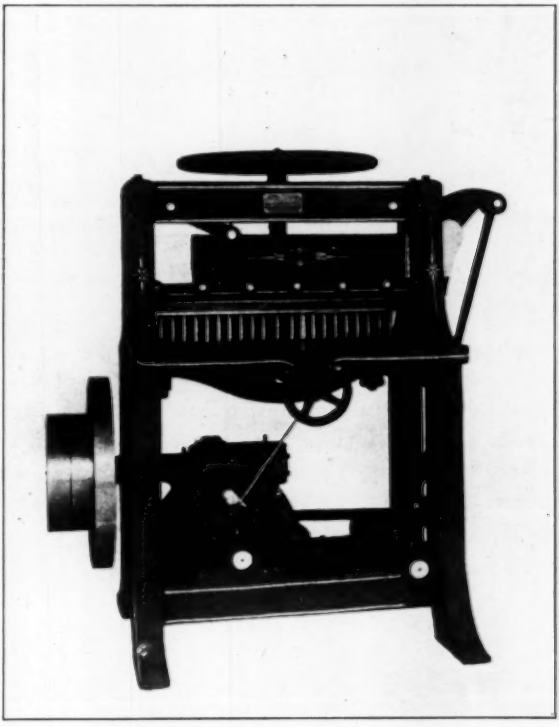

FIG. 11 PHOTOGRAPH OF PAPER CUTTING MACHINE, SHOWING CLUTCH MECHANISM TO BE BROUGHT OUT BY PHOTOGRAPHIC METHODS

ENLARGING NEGATIVES

38 A negative can be reproduced in a larger size by first making a positive in the copying camera, and then making a large negative from the positive by the use of the same instrument.

39 If a negative is enlarged to many times its original size, a granular effect will be noticed. This is caused by magnification of

the emulsion structure which is made up of countless thousands of hills and valleys. This granular effect can be eliminated by slightly over-exposing and greatly over-developing the original negative, and then reducing it to the proper density. The positive should have the same treatment.

40 Reduction does three things:

a It reduces or clears the shadows faster than the high lights. Therefore over-exposure is resorted to in order to increase the density of the shadows in proportion to the high lights, so that they shall bear proper relation to each other after reduction.

b It thins the density of the negative or positive. Therefore over-developing is resorted to in order to have resulting density after reduction.

c It cuts down the hills to the level of the valleys, so that very little if any granular effect is noticeable when the emulsion is magnified.

41 In reproducing negatives either in the original or a larger size, there is a splendid chance for what may be termed "jockeying." A brilliant negative may be made from a very flat one, and vice versa; errors in perspective can be corrected by the method shown in Fig. 5; unequal lighting can be corrected by judicious shading during exposure, and various stunts that will suggest themselves to the ingenious mind can be performed.

X-RAY OR GHOST PHOTOGRAPHS

42 When an illustration is wanted to show clearly some hidden interior part of a machine in relation to and more distinctly than other parts, the usual procedure is to have a wash drawing made in India ink, from which the half-tone is produced. This method is always expensive, and the results are often very unsatisfactory.

43 Fig. 11 shows a power-driven machine for cutting paper, in which the power is transmitted through worm gearing and a positive clutch, all of which is enclosed in an oil tight case, as shown at the lower left hand part of the machine. An illustration showing the worm and worm wheel in mesh was wanted.

44 An engraver was called in, who said he could do the job in a satisfactory manner. Blue prints showing both details and construction were furnished him as a guide to size and shape of the

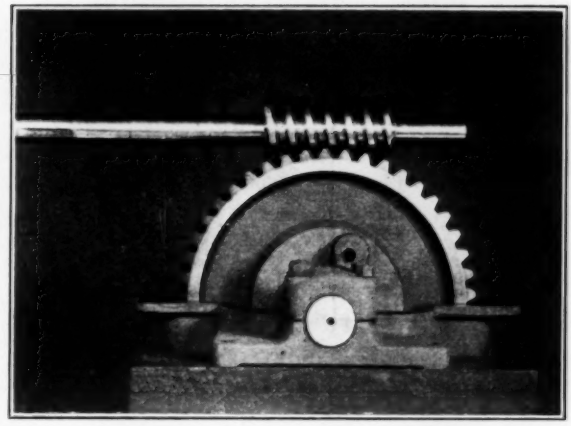

FIG. 12 PHOTOGRAPH OF WORM AND GEAR WITH UPPER PART OF CASE REMOVED

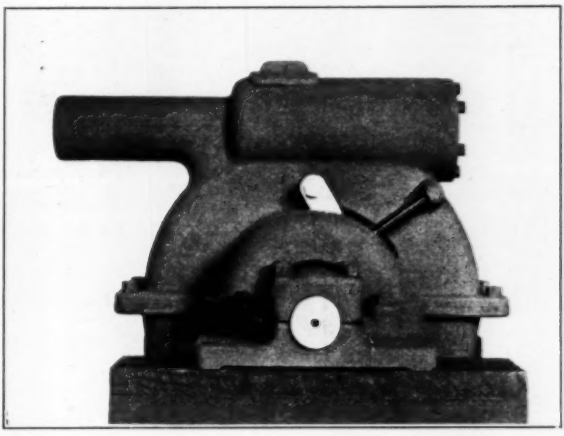

FIG. 13 EXTERIOR OF CASE TO BE PHOTOGRAPHED ON SAME PLATE WITH FIG. 12

various parts, and their appearance when assembled. After repeated attempts, his results were not satisfactory, and it was decided to rely entirely upon photographic methods for the illustration.

45 The case and its contents were removed from the machine, and mounted on a box. The upper part of the case was taken off, leaving the worm wheel and the clutch collar exposed to view. The worm and shaft were removed from the upper part of the case and placed in their proper position in relation to the worm wheel, as shown in Fig. 12. A dark back ground was placed in the rear and an exposure was made. After the exposure the cap was put on the lens, the worm and shaft taken away, and the upper part of the case put in position as in Fig. 13. A light back ground was sub-

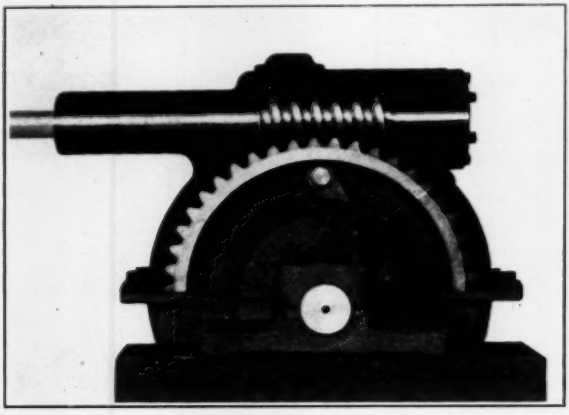

FIG. 14 RESULT OF EXPOSURES FIG. 12 AND 13 ON SAME PLATE

stituted for the dark one, and another exposure made on the same plate, the result of which is shown in Fig. 14.

DEVELOPMENT

46 Of the art of development much has been written, and more has been said, but the fact remains that the only adequate teacher is experience. After many years of experience, the writer would hesitate to attempt to tell in writing how to handle a sensitive plate in development. A few hints however, concerning the behavior of certain mixtures of developer, may be of service.

Too weak a developer makes a flat thin negative.

Too concentrated a developer makes a negative with too much contrast.

Under-developing makes a negative lacking in printing density.

Over-developing makes a thick dense negative requiring a very long time to print.

An under-exposure should be developed with a diluted developer.

An over-exposure should be developed with a concentrated developer well restrained with bromide of potash.

Developers, like artists' colors, should be mixed with brains.

Better choose a moderately slow developer, learn how to use it, and don't let any one persuade you to change it.

PRINTING

47 Printing can be done in so many ways and on such a variety of papers, and the solutions necessary for developing and toning require such care in compounding and handling, that it can in most instances be better and more cheaply done by a professional.

THE PHYSICAL PROPERTIES OF CARBONIC ACID AND THE CONDITIONS OF ITS ECONOMIC STORAGE FOR TRANSPORTATION

By Prof. Reid T. Stewart, Pittsburg, Pa.

Member of the Society

The accompanying tables and charts show in condensed form the results of a recent investigation into the Physical Properties of Carbonic Acid. They furnish the data necessary in investigating the strength and safety of existing carbonic acid cylinders, and in the design of new cylinders on a safe and economic basis. The value of these tables will be apparent when it is considered that each of the hundreds of thousands of the cylinders now in use becomes when charged a reservoir of stored energy, which would in all probability cause loss of both life and property should rupture occur.

2 These tables also furnish sufficient data for determining the conditions that render the weight of the containing cylinder a minimum, and thus make it possible to arrive at the conditions of the most economic storage and transportation of the acid.

3 All previously published tables of carbonic acid are wholly inadequate for the making of even the simplest engineering calculations involving the economic storage and transportation of the gas. For example, the Report to the British Parliament, in 1896, of the Committee on Compressed Gas Cylinders, generally recognized as containing the most authoritative data relating to the physical properties of carbonic acid, is wholly unreliable in its principal table, page 19, for temperatures exceeding 86 deg. fahr.

To be presented at the New York Meeting (December 1908) of The American Society of Mechanical Engineers.

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4 It is believed that the results of the present investigation make it possible for the first time to state positively the conditions under which the weight of the containing cylinder will be a minimum for the customary conditions of storage and transportation of carbonic acid.

5 In Part One of this paper the tables and charts show the physical properties of pure carbon dioxid and are based upon three things: First, the average of the values obtained by Lord Rayleigh and by Leduc for the weight in grams of one liter of purified and dried carbon dioxid, CO_2, under standard conditions; second, the adjusted results of Amagat's classical experiments showing the precise manner in which carbon dioxid differs in its physical actions from the laws of a perfect gas; and, third, the direct application of certain fundamental physical relations and of mathematical and graphical analyses.

6 In Part Two is given the results of the author's experiments on commercial carbonic acid contained in commercial steel cylinders.

7 In Part Three is given a rational method of designing commercial carbonic acid cylinders.

PART I. THE PHYSICAL PROPERTIES OF CARBONIC ACID

8 All the experimental data relating to this subject, so far as available, have been collected and compared. As a proper account of this alone would fill a paper much larger than the present one, only the specific data used as a basis for these new tables and charts will be given. It should be stated, however, that all the data selected for use are of the most reliable character, the original memoirs of the experimenters in every case having been critically examined.

9 All data used have been checked and adjusted by being plotted to a large scale on millimeter coördinate paper, by which means three important clerical errors were discovered and corrected in Amagat's original memoir. Numerous slight adjustments of these data were made in order to have them plot precisely on smooth curves. While making these slight adjustments, great care was taken in every case to have the resulting values follow the apparent law of change.

Weight of Carbonic Acid Gas under Standard Conditions

10 The weight of Carbon Dioxid, CO_2, known commercially as Carbonic Acid Gas, in grams per liter, under the standard conditions of one atmospheric pressure and 0 deg. cent. has heretofore been arrived at by two distinctly different methods, giving appreciably different results. These are, first, by the direct or physical method and, second, by the indirect or chemical method.

THE DIRECT OR PHYSICAL METHOD

11 By this method the weight of a certain volume of carbon dioxid is directly compared with the weight of the same volume of a gas of known mass. For the most accurate determination this latter gas has been either air freed from moisture and carbonic acid, or else purified and dried oxygen.

12 The most reliable values thus far obtained for the density of purified and dried carbon dioxid, under standard conditions, are the following:

TABLE A DENSITY OF CARBON DIOXID

Density of carbon dioxid	For air = 1	For oxygen = 1
According to Lord Rayleigh[1]	1.5291	1.3833
According to Leduc[2]	1.5287	1.3832
Average of these values	1.5289	1.3833

13 The most reliable values for the weight in grams of a liter of air, when freed from moisture and carbonic acid, also of purified and dried oxygen, under 760 mm. pressure and 0 deg. cent. are as follows:

TABLE B WEIGHT OF AIR

Weight of air	At Paris	45 deg. latitude and sea level
According to Lord Rayleigh[1]	1.29327	1.29284
According to Leduc[3]	1.29316	1.29273
Average of these values	1.2932	1.2928

[1] Proceedings Royal Society, vol. 62, p. 209, 1897
[2] Comptes Rendus, vol. 126, . p415, 1898
[3] Annales de Chimie et de Physique, vol. 15, p. 26, 1898

TABLE C WEIGHT OF OXYGEN

Weight of oxygen	At Paris	45 deg. latitude and sea level
According to Lord Rayleigh[1]	1.42952	1.42905
According to Leduc[2]	1.42867	1.42820
Average of these values	1.4291	1.4286

[1] Comptes Rendus, vol. 126, p. 415, 1898.
[2] Annales de Chimie et de Physique, vol. 15, p. 26, 1898.

14 The weight in grams then of one liter of purified and dried carbon dioxid, at 0 deg. cent., 760 mm. pressure, 45 deg. latitude and sea level,

When referred to air = 1.5289 $\times$1.2928 = 1.9765.
When referred to oxygen = 1.3833 $\times$1.4286 = 1.9762.
Average of these values = 1.976.

This is the value that has been used in the preparation of the tables and charts contained in this paper, for the weight of carbonic acid gas under standard atmospheric conditions.

15 It should be noted here that all the other experimental data used were taken from Amagat's classical experiments on the physical properties of carbonic acid. See Tables E, F and G.

THE INDIRECT OR CHEMICAL METHOD

16 Most of the standard works containing physical-chemical tables give a value for the weight of carbon dioxid calculated from the atomic weights of its constituents. For example, on page 223 of Physikalisch-Chemische Tablen, Landolt-Börnstein, Berlin, 1905, we find the weight of carbon dioxid, under standard conditions, stated to be 1.965 g. per liter, a value that differs appreciably from 1.976 as above obtained by the direct or physical method. While it is not stated how this value by Landolt-Börnstein was obtained, it was evidently arrived at in the following manner:

17 The molecular weight of carbon dioxid, CO_2, on the basis of the atomic weight of oxygen = 16, will of course result from taking the sum of the atomic weight of carbon and twice that of oxygen, which, according to the Table of International Atomic Weights for 1907, will be 44.00. Now by dividing one-half the molecular weight of carbon dioxid by the atomic weight of oxygen we get 22.00 $\div$ 16 =

1.375; which by this method should be the density of carbon dioxid when that of oxygen is taken as one. This corresponds to 1.3833 as obtained above by the direct or physical method. Now using the same weight as before for a liter of oxygen under standard conditions, we get by the chemical method, in grams per liter, under standard conditions, the weight of carbon dioxid to be $1.375 \times 1.4286 = 1.964$; which corresponds to 1.976 as above obtained by the direct or physical method. Since this value differs by only one milligram from that given by Landolt-Börnstein, it is safe to assume that their value was calculated directly from the molecular weight of the gas.

18 Because of the deservedly great esteem in which this very extensive and excellent set of tables is held by chemists throughout the world, this value has heretofore been practically universally accepted, notwithstanding the fact that preference should have been given to the values obtained by the direct or physical method, as will appear in what follows.

COMPARISON OF THE TWO METHODS

19 A careful study of the direct or physical method has disclosed no inherent reason why there should be any errors in the results obtained other than those due to the purely instrumental and observational inaccuracies.

20 A similar study of the indirect or chemical method, however, has disclosed the fact that this method will of necessity give results that approximate to the truth just in proportion as the gas under consideration approximates to a perfect gas. Now it is well known that carbon dioxid as compared with oxygen, both being under standard conditions, is very much nearer its liquefying state. It must therefore approximate less closely to the state of a perfect gas than does the oxygen whose mass has been used in the calculation of the weight of the carbon dioxid. On the International Atomic Weight basis of oxygen = 16, therefore, carbon dioxid should actually have a somewhat less volume and a correspondingly greater density than that obtained in the customary way by calculation from its molecular weight.

21 That carbon dioxid is in this respect no exception to the general rule followed by other gases having relatively high critical temperatures is evident from an examination of Table D and Fig. A, which show for nine well known gases, whose densities have been accurately determined by direct weighing, that there is a well defined

relation existing between the errors in the calculated densities and the corresponding critical temperatures of these different gases.

TABLE D SHOWING THE RELATION OF THE ERRORS IN THE DENSITIES OF THE WELL KNOWN GASES TO THEIR CRITICAL TEMPERATURES WHEN THE DENSITIES ARE CALCULATED FROM THE MOLECULAR WEIGHTS OF THE GASES

THIS TABLE CONTAINS ONLY THOSE GASES FOR WHICH ACCURATE DETERMINATIONS OF DENSITY HAVE BEEN MADE BY THE METHOD OF DIRECT WEIGHING

Symbol of Gas	Molecular weight	DENSITY THAT OF AIR = 1		Difference in per cent	Critical temperature Degrees Centigrade
		Calculated	By direct weighing		
SO_2	64.06	2.2122	2.2639*	2.34	+156
Cl_2	70.90	2.4484	2.4910†	1.74	+141
NH_3	17.03	0.5881	0.5971†	1.53	+131
H_2S	34.03	1.1769	1.1895†	1.07	+100
HCl	36.46	1.2591	1.2692†	0.80	+ 52
CO_2	44.00	1.5194	1.5289‡	0.62	+ 31
NO	30.01	1.0363	1.0387‖	0.23	− 93
CO	28.00	0.9669	0.9672§	0.03	−141
H_2	2.016	0.0696	0.0696°	0.00	−204

* Leduc, Comptes Rendus, Vol. 117, p. 219, 1893
† Leduc, Comptes Rendus, Vol. 125, p. 571, 1897
‡ Average of Rayleigh's and Leduc's values used in this paper
‖ Leduc, Comptes Rendus, Vol. 116, p. 322, 1893
§ Lord Rayleigh, Proceedings Royal Society, Vol. 62, p. 204, 1897
° Lord Rayleigh, Proceedings Royal Society, Vol. 53, p. 134, 1893

22 The critical temperatures given in the last column of this table were taken from Castell-Evans Physico-Chemical Tables, 1902, p. 544. Column 2 of molecular weights is based directly upon the Table of International Atomic Weights for 1907. The densities given in column 3 were obtained by multiplying the corresponding molecular weights by the constant 0.345326, or $\frac{1.4286}{32 \times 1.2928}$ which is the weight of oxygen divided by 32 times the weight of air, both under standard conditions; while the densities given in column 4 were taken directly from the original memoirs of the physicists, as noted. Column 5 shows in per cent the errors resulting from calculating the densities of these gases from their molecular weights.

23 Running the eye down the last two columns of Table D, it will be seen, that when the densities of the different gases are calculated from their molecular weights, the resulting errors in density

are related to the corresponding critical temperatures in such manner that the larger error in calculated density always corresponds to the higher critical temperature. This is brought out very strikingly in Fig. A, which shows the errors in the calculated densities of these nine well known gases plotted to scale against their critical temperatures. This chart is self-explanatory, and shows conclusively that the method of calculating the density of a gas from its molecular weight is not exact for such gases as have comparatively high critical temperatures.

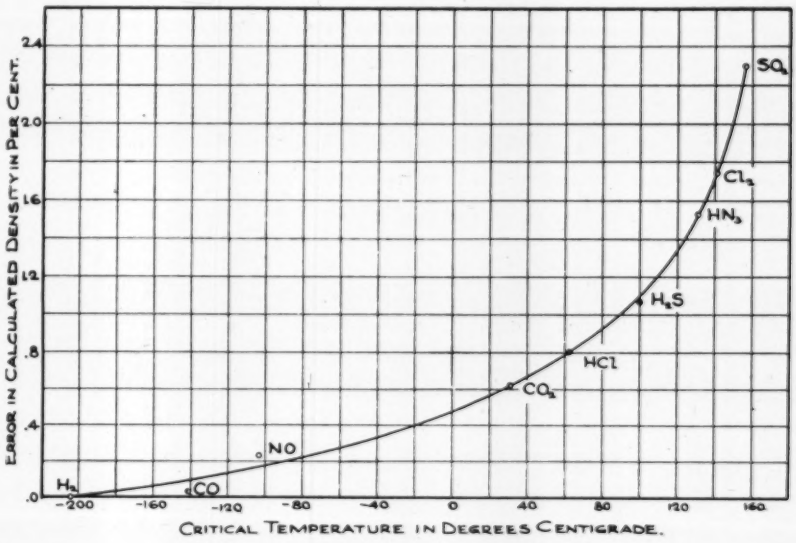

FIG. A CURVE SHOWING THE RELATION OF ERROR IN DENSITY TO THE CRITICAL TEMPERATURE WHEN THE DENSITY OF A GAS IS CALCULATED FROM ITS MOLECULAR WEIGHT

24 This somewhat lengthy review of the inquiry made in order to arrive at the most reliable value for the weight in grams of a liter of carbon dioxid under standard conditions is here given solely to satisfy those critically inclined that no error has been made by not using the value commonly found in such standard works as Physikalisch-Chemische Tablen, Landolt-Börnstein, Berlin, 1905.

AMAGAT'S EXPERIMENTAL RESEARCHES ON CARBONIC ACID

25 Emile H. Amagat, the celebrated French Physicist, is the author of at least two score memoirs relating to gases. Two of these

contain valuable experimental data on carbon dioxid. These are: Sur la détermination de la Densité des Gaz et de leur Vapeur Saturée, Comptes Rendus, vol. 114, p. 1093 and p. 1322, 1892; Journal de Physique, p. 288, 1892; Mémoires sur l'Elasticité et la Dilatation des Fluides jusqu'aux trés hautes Pressions, Annales de Chimie et de Physique, vol. 29, 1893.

26 From these two memoirs, the following data were abstracted and form the basis of all the tables contained in Part 1. These data are:

Table E, stating the density of the liquid and of the saturated vapor, also the vapor tension of carbon dioxid in atmospheres, for temperatures ranging from 0 deg. cent. to the critical temperature, 31.35 deg. cent.

Table F, stating the products of the pressures and the corresponding volumes, PV, of carbon dioxid, for the temperatures and pressures given.

Table G, supplementary to Table F, stating the values of PV at or near which the curves resulting from plotting Table F make abrupt changes in direction.

TABLE E AMAGAT'S DATA FOR CARBON DIOXID

T Degrees	DENSITY		Maximum vapor tension	T Degrees	DENSITY		Maximum vapor tension
	Liquid	Saturated vapor			Liquid	Saturated vapor	
0	0.914	0.096	34.3	18.00	0.786	0.176	53.8
1	0.910	0.099	35.2	19.00	0.776	0.183	55.0
2	0.906	0.103	36.1	20.00	0.766	0.190	56.3
3	0.900	0.106	37.0	21.00	0.755	0.199	57.6
4	0.894	0.110	38.0	22.00	0.743	0.208	59.0
5	0.888	0.114	39.0	23.00	0.731	0.217	60.4
6	0.882	0.117	40.0	24.00	0.717	0.228	61.8
7	0.876	0.121	41.0	25.00	0.703	0.240	63.3
8	0.869	0.125	42.0	26.00	0.688	0.252	64.7
9	0.863	0.129	43.1	27.00	0.671	0.266	66.2
10	0.856	0.133	44.2	28.00	0.653	0.282	67.7
11	0.848	0.137	45.3	29.00	0.630	0.303	69.2
12	0.841	0.142	46.4	30.00	0.598	0.334	70.7
13	0.831	0.147	47.5	30.50	0.574	0.356	71.5
14	0.822	0.152	48.7	31.00	0.536	0.392	72.3
15	0.814	0.158	50.0	31.25	0.497	0.422	72.8
16	0.804	0.164	51.2	31.35	0.464	0.464	72.9
17	0.796	0.170	52.4				

TABLE F AMAGAT'S VALUES OF PV FOR CARBON DIOXID

P Atmosphere	0 deg. Cent.	10 deg. Cent.	20 deg. Cent.	30 deg. Cent.	40 deg. Cent.	50 deg. Cent.	60 deg. Cent.
1	1.0000	.....	.....	.....	.....	.....	.....
50	0.1050	0.1145	0.6800	0.7750	0.8500	0.9200	0.9840
75	0.1530	0.1630	0.1800	0.2190	0.6200	0.7470	0.8410
100	0.2020	0.2130	0.2285	0.2550	0.3090	0.4910	0.6610
125	0.2490	0.2620	0.2785	0.3000	0.3350	0.3950	0.5100
150	0.2950	0.3090	0.3260	0.3460	0.3770	0.4190	0.4850
175	0.3405	0.3550	0.3725	0.3930	0.4215	0.4570	0.5055
200	0.3850	0.4010	0.4190	0.4400	0.4675	0.5000	0.5425
225	0.4305	0.4455	0.4655	0.4875	0.5130	0.5425	0.5825
250	0.4740	0.4900	0.5100	0.5335	0.5580	0.5865	0.6250
275	0.5170	0.5340	0.5545	0.5775	0.6040	0.6330	0.6675
300	0.5595	0.5775	0.5985	0.6225	0.6485	0.6765	0.7100
350	0.6445	0.6640	0.6850	0.7090	0.7365	0.7650	0.7980
400	0.7280	0.7475	0.7710	0.7950	0.8230	0.8515	0.8840
450	0.8090	0.8310	0.8550	0.8800	0.9075	0.9365	0.9690
500	0.8905	0.9130	0.9380	0.9630	0.9900	1.0210	1.0540
550	0.9700	0.9935	1.0200	1.0465	1.0740	1.1035	1.1370
600	1.0495	1.0730	1.0995	1.1275	1.1570	1.1865	1.2190
650	1.1275	1.1530	1.1800	1.2075	1.2375	1.2680	1.3010
700	1.2055	1.2320	1.2590	1.2890	1.3190	1.3500	1.3825
750	1.2815	1.3105	1.3395	1.3700	1.4000	1.4315	1.4640
800	1.3580	1.3870	1.4170	1.4475	1.4790	1.5105	1.5435
850	1.4340	1.4625	1.4935	1.5245	1.5570	1.5885	1.6225
900	1.5090	1.5385	1.5685	1.6000	1.6325	1.6650	1.6995
950	1.5830	1.6115	1.6430	1.6740	1.7065	1.7395	1.7745
1000	1.6560	1.6850	1.7160	1.7480	1.7800	1.8140	1.8475

P	70 deg.	80 deg.	90 deg.	100 deg.	137 deg.	198 deg.	258 deg.
1	.....	.....	.....	.....	.....	.....	.....
50	1.0430	1.0960	1.1530	1.2065	1.3800	.....	.....
75	0.9180	0.9880	1.0515	1.1180	1.3185	1.6150	1.8670
100	0.7770	0.8725	0.9535	1.0300	1.2590	1.5820	1.8470
125	0.6430	0.7590	0.8580	0.9470	1.2050	1.5530	1.8310
150	0.5750	0.6805	0.7815	0.8780	1.1585	1.5295	1.8180
175	0.5730	0.6515	0.7410	0.8320	1.1230	1.5100	1.8095
200	0.5955	0.6600	0.7315	0.8145	1.0960	1.4960	1.8040
225	0.6285	0.6815	0.7460	0.8175	1.0835	1.4890	1.8035
250	0.6670	0.7135	0.7690	0.8355	1.0810	1.4870	1.8060
275	0.7070	0.7515	0.8015	0.8600	1.0885	1.4875	1.8115
300	0.7485	0.7900	0.8375	0.8900	1.1080	1.4935	1.8200
350	0.8325	0.8725	0.9135	0.9615	1.1565	1.5210	1.8465
400	0.9180	0.9560	0.9960	1.0385	1.2175	1.5630	1.8830
450	1.0035	1.0400	1.0775	1.1190	1.2880	1.6160	1.9280
500	1.0880	1.1240	1.1610	1.2005	1.3620	1.6775	.....
550	1.1720	1.2085	1.2430	1.2830	1.4400	1.7450	.....
600	1.2540	1.2900	1.3265	1.3655	1.5180	1.8120	.....
650	1.3360	1.3725	1.4085	1.4475	1.5960	1.8835	.....
700	1.4170	1.4535	1.4900	1.5285	1.6760	1.9560	.....
750	1.4985	1.5335	1.5705	1.6100	1.7565	2.0330	.....
800	1.5780	1.6140	1.6505	1.6890	1.8355	2.1080	.....
850	1.6575	1.6925	1.7285	1.7680	1.9150	2.1860	.....
900	1.7345	1.7710	1.8075	1.8460	1.9940	2.2600	.....
950	1.8100	1.8470	1.8845	1.9230	2.0720	2.3350	.....
1000	1.8840	1.9210	1.9590	1.9990	.....	.....	.....

TABLE G CARBON DIOXID

AMAGAT'S SUPPLEMENTARY TABLE FOR VALUES OF PV

P Atmospheres	0 deg. Cent.	10 deg. Cent.	20 deg. Cent.	30 deg. Cent.	32 deg. Cent.	35 deg. Cent.	40 deg. Cent.	50 deg. Cent.	60 deg. Cent.	70 deg. Cent.	80 deg. Cent.	90 deg. Cent.	100 deg. Cent.
31	.7380	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
33	.7120	.7860	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
34	.6990	.7750	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
35	.0750	.7640	.8350	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
37	.0790	.7420	.8170	.8820	.....	.....	.....	.....	.....	.....	.....	.....	.....
40	.....	.7060	.7895	.8590	.8750	.8920	.9235	.....	.....	.....	.....	.....	.....
44	.....	.6530	.7490	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
45	.....	.1050	.7380	.8190	.8350	.8555	.8880	.9520	1.0110	1.0660	.....	.....	.....
48	.....	.....	.7060	.7930	.....	.....	.8670	.9330	0.9950	1.0520	.....	.....	.....
50	.1050	.1145	.6800	.7750	.7920	.8155	.8525	.9210	0.9840	1.0430	1.0980	1.1535	1.2070
53	.....	.....	.6370	.7460	.....	.....	.8300	.9020	0.9680	1.0280	1.0850	1.1420	1.1960
55	.....	.....	.6050	.7260	.7455	.7720	.8135	.8890	0.9570	1.0185	1.0760	1.1340	1.1885
56	.....	.....	.5850	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
57	.....	.....	.1480	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
60	.....	.....	.1520	.6680	.6935	.7245	.7720	.8555	0.9285	0.9940	1.0540	1.1130	1.1710
65	.....	.....	.....	.5950	.6290	.6690	.7260	.8200	0.8990	0.9690	1.0325	1.0930	1.1530
68	.....	.....	.....	.5350	.5780	.6310	.6950	.7970	0.8810	0.9530	1.0190	1.0810	1.1420
70	.....	.....	.....	.4700	.5400	.6020	.6730	.7820	0.8685	0.9430	1.0100	1.0730	1.1350
71	.....	.....	.....	.2300	.....	.....	.....	.....	.....	.....	.....	.....	.....
72	.....	.....	.....	.2230	.4910	.....	.....	.....	.....	.....	.....	.....	.....
73	.....	.....	.....	.....	.4600	.....	.....	.....	.....	.....	.....	.....	.....
74	.....	.....	.....	.2190	.4050	.5310	.....	.....	.....	.....	.....	.....	.....
74.5	.....	.....	.....	.....	.3400	.....	.....	.....	.....	.....	.....	.....	.....
75	.....	.....	.....	.2190	.2680	.5100	.6130	.7410	0.8360	0.9170	0.9880	1.0535	1.1180
76	.....	.....	.....	.....	.2495	.4850	.....	.....	.....	.....	.....	.....	.....
78	.....	.....	.....	.2205	.2410	.4200	.....	.....	.....	.....	.....	.....	.....
80	.....	.....	.....	.2225	.....	.3180	.5400	.7000	0.8031	0.8900	0.9660	1.0335	1.1005
82	.....	.....	.....	.....	.....	.2810	.5030	.....	.....	.....	.....	.....	.....
85	.....	.....	.....	.....	.....	.2670	.4350	.6510	0.7690	0.8630	0.9425	1.0135	1.0835
90	.....	.....	.....	.....	.....	.2650	.3410	.5990	0.7340	0.8350	0.9190	0.9935	1.0655
95	.....	.....	.....	.....	.....	.....	.3140	.5460	0.6980	0.8060	0.8960	0.9735	1.0480
100	.....	.....	.....	.....	.....	.....	.3090	.4910	0.6610	0.7770	0.8720	0.9540	1.0305
110	.....	.....	.....	.....	.....	.....	.3130	.4170	0.5880	0.7210	0.8240	0.9140	0.9970

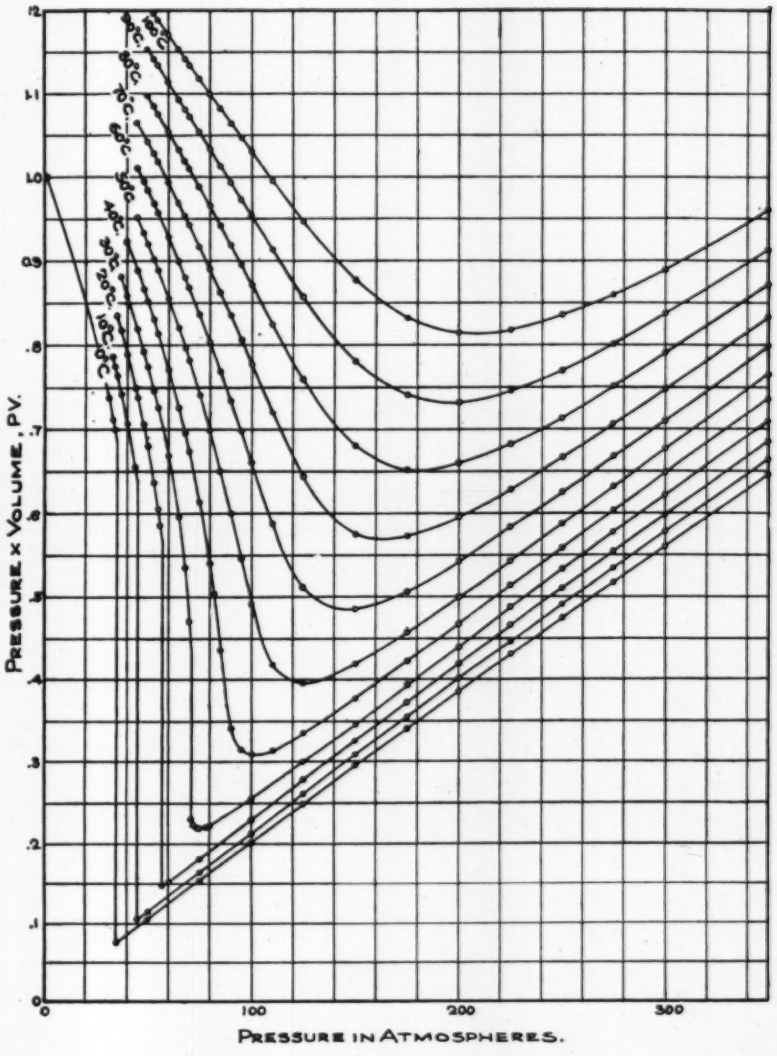

FIG. B CURVES SHOWING THE RELATION OF AMAGAT'S *PV* VALUES TO THE PRESSURE OF CARBONIC ACID

Tables of the Physical Properties of Carbonic Acid, as Calculated by the Author in 1904 and Recalculated under his Direction by Frank P. Kramer in 1907

27 Table 1 shows, in metric units, the physical properties of the liquid and of the saturated vapor of carbon dioxid, for temperatures ranging from 0 deg. cent. to the critical temperature, 31.35 deg. cent.

28 In this table the liquid and the vapor are assumed to be in the condition in which they exist in a cylinder when partially filled with liquid carbon dioxid, the space overlying the liquid being filled with the saturated vapor. A full explanation of the critical temperature and of these states will be found elsewhere in this paper under the caption, The Three States of Carbonic Acid.

29 Columns 2, 4 and 5 of this table are based directly upon Amagat's experimental results, Table E, the only difference being that the slight irregularities of Amagat's values have been carefully adjusted in Table 1. This was accomplished by plotting his results to a large scale on millimeter coördinate paper, after which the plotted values were slightly shifted, where necessary, in order to make them plot precisely on smooth curves, and thus bring them into closer agreement with the apparent laws involved.

30 Column 3 was then calculated from column 2, by means of the conversion factor 1.03329, which is the fluid pressure in kilograms per square centimeter corresponding to one atmosphere. This factor was taken from Hering's Conversion Tables, vol. 1, p. 66, 1904, and was checked before using, by independent calculation.

31 Columns 6 and 7 were calculated from columns 4 and 5, respectively, by taking the reciprocals of the corresponding entries in these columns. It will be observed that this simple relation is due to the fact that a liter of water under standard conditions weighs one kilogram. That is to say, the volumes in liters per kilogram should be the reciprocals of the corresponding densities.

32 After these calculations were made and entered in the preliminary table, each column so calculated was checked by being plotted to a large scale on millimeter coördinate paper; after which the final figure, where found necessary, was adjusted so as to bring the plotted result precisely on the curve representing the apparent laws involved. This final adjustment was necessary only when for obvious reasons the reciprocal had to be stated with somewhat greater precision than that of the constant from which it was obtained.

33 Table 2 shows in British units the physical properties of the liquid and of the saturated vapor of carbon dioxid, for temperatures ranging from 32 deg. fahr. to the critical temperature, 88.4 deg. fahr. For explanation of the critical temperature, etc., see elsewhere in this paper, The Three States of Carbonic Acid.

34 This table was prepared from Table 1 in the following manner: First, columns 2, 4 and 5 of Table 1 were plotted to large scales on millimeter coördinate paper, the vertical scale of each being centigrade degrees; second, on each of these charts a second vertical scale of equivalent fahrenheit degrees was then constructed; and third, from curves adjusted to the values thus plotted to centigrade degrees there were then read the equivalent values from the fahrenheit scales.

35 This graphical method of conversion from one to the other temperature scale worked very satisfactorily indeed. It of course gives theoretically correct results, even when, as in this case, the equations of the curves involved are unknown. In this manner columns 3, 4 and 5 of Table 2 were obtained, showing in British units the fundamental relations of temperature, pressure, and density for both the liquid and the saturated vapor of carbon dioxid, for temperatures less than the critical temperature, 88.4 deg. fahr.

36 Column 2 was then calculated from column 3 by use of the conversion factor 14.697, which is the equivalent in pounds of one atmospheric pressure. Columns 6 and 8 were calculated from 4 by use of the conversion factors 62.43 and 8.345, which are the respective weights in pounds of 1 cu. ft. and 1 U. S. gal. of pure water at its maximum density; and columns 7 and 9 were similarly calculated from 5. Finally columns 10 and 11 were calculated respectively from 6 and 7, as in Table 1, by taking the reciprocals of the corresponding constants in those columns.

37 After all these calculations were made, and before the results were finally entered in the table, each column, as in Table 1, was adjusted to plot precisely on smooth curves.

38 Table 3 shows the pressures of carbon dioxid, in pounds per square inch, corresponding to densities ranging from 0.50 to 1.00, that of water at its maximum density being unity, and for temperatures ranging from 0 deg. to 100 deg. cent. It was calculated directly from Amagat's PV values as follows:

39 First, a table of densities corresponding to each PV value of Tables F and G was calculated by means of the formula

$$G = \frac{G_o P}{C} = \frac{0.001976 P}{C} \qquad (1)$$

where

G = the density of carbon dioxid corresponding to any tabular pressure, that of water at 4 deg. cent. being unity.

$G_0 = 0.001976$ = the density of carbon dioxid at 760 mm., 0 deg. cent., 45 deg. latitude, and sea level.

P = the pressure exerted by the carbon dioxid in standard atmospheres.

C = the tabular value of PV as read from Amagat's Tables F and G.

40 Second, these calculated values were then plotted in a manner similar to Fig. 2, but to a large scale on millimeter coördinate paper, the horizontal scale representing the densities referred to water and the vertical scale the corresponding pressures in pounds per square inch; the atmospheric pressures, before plotting, having been reduced to the equivalent pressures in pounds per square inch. Smooth curves were then adjusted to these plotted values, after which the entries of Table 3 were obtained by direct readings from these adjusted curves.

DERIVATION OF FORMULA ONE

41 This formula is based upon the following considerations:—

42 First, the density of a fluid referred to water will be the same as its weight in kilograms per liter. The density of carbon dioxid therefore, when referred to water at 4 deg. cent. will be 0.001976 under standard conditions, since a liter under these conditions weighs 1.976 g. For the derivation of this value see, elsewhere in this paper, the discussion of Lord Rayleigh's and Leduc's experimental determinations relating to carbon dioxid.

43 Second, Amagat's Tables F and G give for the different temperatures and pressures of carbon dioxid the results obtained by multiplying each pressure by its corresponding volume, the result being expressed in terms of this product under the standard conditions of one atmospheric pressure and 0 deg. cent. That is to say,

$$PV = CP_0V_0 = CV_0$$

where P_0 represents one atmospheric pressure and V_0 the corresponding volume at 0 deg. cent. From this we get the ratio of volume

$$\frac{V_0}{V} = \frac{P}{C}$$

Since the density of a definite mass of gas is always inversely as the volume that it occupies, we get

$$\frac{G}{G_o} = \frac{V_o}{V} = \frac{P}{C}$$

or

$$G = G_o \frac{P}{C} = W \frac{P}{C}$$

where W is the weight in kilograms per liter under the standard conditions of one atmospheric pressure, 0 deg. cent., 45 deg. latitude, and sea level; which for purified and dried carbon dioxid is 0.001976.

44 Table 4 gives the pressures of carbon dioxid corresponding to densities ranging from 0.50 to 1.00, that of water at its maximum density being unity, and for temperatures ranging from 32 deg. to 212 deg. fahr. It should be noted, for that portion of the table corresponding to temperatures less than the critical temperature of 88.4 deg. fahr. and lying above the line AB, that the total weight of carbon dioxid contained in a cylinder is made up of two parts, one of which is the liquid portion and the other the vaporous portion which always fills the volume of the cylinder not occupied by the liquid. For this portion of the table the combined density of the liquid and its overlying vapor is here tabulated. A further explanation of this part of the table will be found elsewhere in this paper under the caption, Combined Density of the Liquid and Saturated Vapor.

45 This table was obtained as follows: First, a chart, constructed to a large scale on millimeter coördinate paper, the horizontal scale representing pressures in pounds per square inch, and the vertical scale temperatures in degrees centigrade, was made from readings taken from the large scale chart, similar to Fig. 2, that was used in the preparation of Table 3. Second, a fahrenheit temperature scale was interpolated on this chart, after which the pressures and corresponding densities for the different fahrenheit temperatures were read and plotted to a large scale in a manner similar to Fig. 2, the temperature curves in this case being, however, fahrenheit instead of centigrade degrees. Third, the entries of this table were then obtained by direct readings from the fahrenheit temperature curves of this final chart.

46 This proved a most satisfactory method for obtaining the values of pressures in pounds corresponding to given densities and

fahrenheit temperatures, from Amagat's PV values corresponding to pressures in atmospheres and centigrade temperatures. This method when carried out to the large scales used, gives results that are fully as precise as the accuracy of Amagat's experimental results warrant, and in addition, like other similar graphical methods, is practically self-checking.

47 Table 5 shows, for different temperatures and combined densities, or proportions of filling in pounds of carbonic acid per pound of water capacity, the portion of the cylinder volume occupied by the liquid part of the carbonic acid contained.

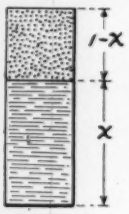

FIG. C

48 The total weight of carbonic acid charged into a cylinder, when below the critical temperature of 88.4 deg. fahr., will ordinarily be made up of a liquid portion and of a portion that is in the state of a saturated vapor, which overlies the liquid and fills the volume of the cylinder unoccupied by it.

49 This table was calculated by means of the following formula, derived as follows:

Let

x = the portion of the cylinder volume that is occupied by the liquid portion of the carbonic acid.

$1-x$ = the portion occupied by the saturated vapor.

G_l = the density of the liquid carbonic acid, that of pure water at 4 deg. cent. being unity.

G_v = ditto of the saturated vapor of carbonic acid.

G = combined density of the liquid and saturated vapor of carbonic acid, or the proportion of filling in pounds of carbonic acid per pound of water capacity.

Then the volume of the liquid portion x multiplied by its density G_l, or $x\,G_l$, added to the volume of the saturated vapor $1-x$, multiplied by its density G_v, or $(1-x)G_v$,

must equal the volume of the cylinder 1, multiplied by the combined density G; or

$$x\ G_l + (1-x)\ G_v = G$$

or

$$x = \frac{G - G_v}{G_l - G_v} \qquad (2)$$

That is, the portion of the cylinder volume occupied by the liquid part of the carbonic acid contained is equal to the difference of the combined density and that of the saturated vapor, divided by the difference of the density of the liquid and that of the saturated vapor.

50 When applying this formula it should be remembered that the liquid density here involved is that given in column 4 of Tables 1 and 2; and is for the liquid when in contact with its saturated vapor, that is to say, when it is just on the point of being converted into a vapor. The saturated vapor densities to be used are given in column 5 of the same tables.

The Three States of Carbonic Acid

51 Carbonic acid as commercially handled may exist in three distinctly different states: the gaseous, the vaporous, and the liquid. Other states than these have no bearing upon questions of commercial storage and transportation, and will not therefore be considered in this paper.

52 Commercial carbonic acid is manufactured, collected as a by-product, or from natural sources, as either a gas or a superheated vapor. After being compressed and cooled sufficiently this gas or vapor is converted into a liquid, which is charged into steel cylinders for transportation to the consumer.

53 From the standpoint of the physicist the critical temperature is that temperature above which a substance always exists in the gaseous state. For temperatures above the critical temperature no substance has yet been reduced to the liquid state by any pressure, however great; while for temperatures below the critical temperature all the commonly occurring gases have been liquefied.

54 The critical temperature of purified and dried carbon dioxid, as determined by Amagat, is 31.35 deg. cent., or 88.4 deg. fahr. He

has compressed the gas while above this temperature to a pressure approximating 15 000 lb. per square inch, and thus to a density about 10 per cent greater than that of water, without reducing it to a liquid. For any temperature below this critical temperature he found a definite and fixed pressure at which the carbon dioxid could be reduced to the liquid state. The pressures at which liquefaction occurs for the different temperatures are given in columns 2 and 3 of Table 1, in metric units, and in the same columns of Table 2, in British units.

GASEOUS, SATURATED AND LIQUID STATES

55 For all temperatures above the critical temperature of 31.35 deg. cent., or 88.4 deg. fahr., carbon dioxid is always found in the gaseous state. While in this state it necessarily exists as a homogeneous substance that fills all parts of the containing vessel, just as would the more perfect gases, oxygen and hydrogen. While in this state it cannot be reduced to a liquid by any pressure, however great.

56 The relations of density, temperature and pressure of purified and dried gaseous carbon dioxid are given in the columns corresponding to temperatures from 31.35 to 100 deg. cent., inclusive, of Table 3, and to temperatures from 88.4 to 212 deg. fahr. inclusive, of Table 4.

57 Carbon dioxid exists as a saturated vapor when just on the point of being converted into a liquid. It can exist in this state only when its temperature is less than the critical temperature of 31.35 deg. cent., or 88.4 deg. fahr. When in this state, just as in the case of saturated steam, for every pressure there is a corresponding definite temperature and density. These relations of temperature, pressure and density are given in Metric units in Table 1, and in British units in Table 2.

58 Carbon dioxid can exist in the liquid state, first, only for temperatures less than the critical temperature of 31.35 deg. cent., or 88.4 deg. fahr., and, second, for any such temperature, only for pressures that are equal to or greater than the saturated vapor pressure corresponding to that temperature.

59 There are two entirely distinct conditions under which liquid carbon dioxid may be stored for transportation. It is extremely important that these two conditions should be clearly understood. They are, first, when the liquid carbon dioxid partially fills the containing cylinder, and second, when it entirely fills the containing cylinder. The importance of differentiating these two conditions is apparent when it is considered that the pressures exerted on the

walls of the cylinders under these two conditions may be widely different for any given temperature, as will appear from what follows.

LIQUID STATE FOR PARTIAL FILLING

60 For this case the relation of temperature, pressure, and density of purified liquid carbon dioxid are given in metric units in columns 1 to 4 inclusive of Table 1, and in British units in the same columns of Table 2.

61 These two tables state the properties of liquid carbon dioxid when in the condition of just having been condensed from the vaporous state into a liquid, or just on the point of being converted from a liquid into the vaporous state. This is always the state of the flush liquid portion of the contents of a cylinder when the liquid does not entirely fill it, the space unoccupied by the liquid being of course filled with a saturated vapor.

LIQUID STATE FOR COMPLETE FILLING

62 When the pressure on the liquid is greater than that exerted by the saturated vapor at the same temperature it is evident that no saturated vapor can exist in contact with the liquid, so that for this condition the liquid carbon dioxid must entirely fill the containing cylinder.

63 The relations of density, temperature, and pressure for this condition are those shown as lying below the line AB of Tables 3 and 4. For example, in Table 4, for a temperature of 70 deg. fahr. the pressures corresponding to densities of 0.80, 0.90, and 1.00 are respectively 1060, 2120, and 4940 lb. per square inch; while for the same temperature for the condition of partial liquid filling of the cylinder, corresponding to combined densities of the liquid and the overlying saturated vapor ranging from 0.50 to 0.75, the pressure is constant, and equals 849 lb. per square inch.

COMBINED DENSITY OF THE LIQUID AND SATURATED VAPOR

64 In cylinders under the ordinary conditions of storage and transportation, for temperatures less than the critical temperature of 31.35 deg. cent., or 88.4 deg. fahr., we have to deal with the carbonic acid in both the liquid and the vaporous states at the same time.

That is to say, of the total weight of carbonic acid charged into a cylinder a portion is in the liquid state while the remainder exists in the state of a saturated vapor filling the volume of the cylinder that is unoccupied by the liquid portion. In the commercial storage of carbonic acid we are therefore obliged to deal with the combined density of the liquid and its overlying vapor. The portions of the cylinder volume that are occupied by the liquid part of the carbonic acid charged into a cylinder have been worked out for combined densities ranging from 0.50 to 1.00 and are given in Table 5.

65 The portions of Tables 3 and 4 above the line AB show the relations of the density, temperature and pressure of carbon dioxid for the condition of partial liquid filling of the cylinder. The densities in column 1 for this portion of each of these tables are the combined densities of the liquid and its overlying vapor, for the different conditions tabulated; and are equal, in each case, to their combined weights divided by the weight of their combined volumes of water, the water being at its maximum density, or at a temperature of 4 deg. cent., or 39.2 deg. fahr. In other words, the densities here given are the same as the corresponding "proportion of filling in pounds of carbonic acid per pound of water capacity." That is to say, a tabular density of 0.62 means, for any portion of these tables, that the weight of carbonic acid contained is 62 per cent of the weight of the water that would be required to fill the cylinder entirely, the water being pure and at its maximum density.

66 It will be observed that for this portion of these tables, namely, that lying above the line AB, there is a fixed relation existing between the temperature and pressure irrespective of the value of the combined density. For example, for a temperature of 60 deg. fahr., Table 4, the pressure is 744 lb. per square inch for all combined densities of from 0.50 to 0.80 inclusive. This means for this temperature and range of density, that the cylinder contains both liquid carbon dioxid and its saturated vapor; the portion of the cylinder volume occupied by the liquid increasing, and that occupied by the saturated vapor diminishing, as the combined density increases.

67 Now so long as there is vapor present, that is, so long as the liquid does not completely fill the cylinder, the pressure exerted will of course be that due to the saturated vapor alone, and is therefore constant for any fixed temperature; and of course entirely independent of the portion of the cylinder volume that is filled with the liquid.

68 When the cylinder, however, becomes entirely filled with the

liquid, so that no space remains for vapor, then the pressure will cease to be constant for a given temperature. By referring to Table 4, this is seen to occur for a temperature of 50 deg. fahr. between the densities of 0.85 and 0.86; for 60 deg. fahr., between those of 0.80 and 0.81; for 70 deg. fahr., between those of 0.75 and 0.76; and for 80 deg. fahr., between those of 0.67 and 0.68.

PORTION OF CYLINDER VOLUME OCCUPIED BY THE LIQUID

69 In the commercial storage and transportation of carbonic acid, for temperatures less than the critical temperature of 88.4 deg. fahr. it is a matter of interest to know just what portions of the cylinder volume are occupied by the liquid and by the saturated vapor. An investigation of this matter has resulted in the production of Table 5; which shows for different temperatures and combined densities, which latter is of course the same thing as the "proportion of filling in pounds of carbonic acid per pound of water capacity," the precise portion of the cylinder volume that is occupied by the liquid portion of the carbonic acid contained. For example, if a cylinder be charged, at a temperature of 60 deg. fahr. to 0.62 of its water capacity by weight, then, from Table 5, we find that the resulting liquid part of the carbonic acid will occupy 0.708 of the cylinder volume, the remaining portion, or 0.292, being occupied by the saturated vapor. If now, the temperature of the cylinder and its contents, for the same proportion of filling, be elevated to 80 deg. fahr., then the liquid will occupy according to this table, 0.863 of the cylinder volume. This increase in the volume of the liquid portion of the cylinder contents is due, first, to the expansion of the original liquid portion under the influence of the rise in temperature, and second, to the condensation to the liquid state of a portion of the original saturated vapor. From the table, this action is seen to continue, as the temperature rises, until a temperature somewhere between 84 and 86 deg. fahr. is reached, at which point all the vapor is condensed, and the whole of the carbonic acid content is in the liquid form, and of course fills the entire cylinder volume.

70 After the completion of Table 5 it was discovered that a sealed glass tube containing liquid carbonic acid, procured from Germany for experimental purposes, did not follow the law of increase of liquid volume with rise of temperature as exhibited by this table. On the contrary, as the temperature of the tube was elevated the volume of the liquid gradually decreased and altogether vanished before the

critical temperature was reached. This unexpected action seemed inexplicable at first, but an investigation revealed the curious law that is apparent from an inspection of Fig. 3, which has been constructed for a much larger range in combined density than Table 5.

71 An inspection of Fig. 3 shows that for combined densities greater than the critical density of 0.46 an increase in temperature is always attended by an increase in the liquid volume, while for densities less than 0.46 the law is reversed, so that any increase in temperature is attended by a decrease in liquid volume. Upon making a determination for the combined density of the carbonic acid in the sealed glass tube, which was found to be 0.3, that of Table 5 being 0.5 to 1.0, the matter became quite clear when viewed in the light of the law revealed by Fig. 3.

PRESSURES IN POUNDS OF CARBONIC ACID PER POUND OF WATER CAPACITY CORRESPONDING TO DIFFERENT DENSITIES OR PROPORTIONS OF FILLING

72 These pressures may be read in metric units, directly from Table 3, and in British units from Table 4, for a large range in both temperature and density. The densities here given corresponding to pressures lying above the line AB are the combined densities, as fully explained elsewhere in this paper under the caption "Combined densities of the liquid and saturated vapor." The densities given in column 1 are for all parts of the table the same as the "proportion of filling in pounds of carbonic acid per pound of water capacity." Thus for a cylinder charged with carbonic acid so as to contain 0.62 of the weight of its capacity in water, or a density of 0.62, the pressures corresponding to temperatures of 50, 80 and 110 deg. fahr. are respectively 650, 965, and 1560 pounds per square inch; while those corresponding to the same temperatures for a cylinder charged to 0.84 of its water capacity would be respectively 650, 1780 and 3115 pounds. This shows that for these two proportions of filling, while at 50 deg. fahr. the pressures are precisely the same, the cylinder containing the greater proportion of filling will be subjected to a pressure that is 84 per cent greater at 80 deg. fahr., and that is 99 per cent greater at 110 deg. fahr.

TABLE 1 PHYSICAL PROPERTIES OF THE LIQUID AND THE SATURATED VAPOR OF CARBONIC ACID FROM 0 DEG. CENT. TO THE CRITICAL TEMPERATURE 31.35 DEG. CENT.

PRESSURE FACTORS.—For pounds per square inch multiply by 14.697 for Column 2

WEIGHT FACTORS for Columns 4&5.

For grams per cubic centimeter	multiply by	1.
" kilograms per cubic meter	" "	1000.
" kilograms per liter	" "	1.
" pounds per cubic inch	" "	0.03613
" pounds per cubic foot	" "	62.43
" pounds per gallon (U.S.)	" "	8.345

VOLUME FACTORS for Columns 6&7

For cubic centimeters per gram	multiply by	1.
" cubic meters per kilogram	" "	0.001
" cubic inches per pound	" "	27.68
" cubic feet per pound	" "	0.01602
" gallons (U.S.) per pound	" "	0.1198

Temperature Degrees Centigrade	Pressure, Saturated Vapor		Density, That of Water at 4°C.=1		Volume, Liters per Kilogram	
	Atmospheres	Kilograms per Sq.Cent.	Liquid	Vapor	Liquid	Vapor
0	34.3	35.4	.916	.096	1.092	10.42
1	35.2	36.35	.911	.099	1.098	10.09
2	36.1	37.3	.906	.1025	1.104	9.76
3	37.05	38.3	.900	.106	1.111	9.44
4	38.0	39.3	.894	.1095	1.118	9.13
5	39.0	40.3	.888	.113	1.126	8.84
6	40.0	41.35	.882	.117	1.134	8.55
7	41.0	42.4	.876	.121	1.142	8.27
8	42.05	43.45	.869	.125	1.151	8.00
9	43.1	44.55	.862	.129	1.160	7.75
10	44.2	45.65	.855	.133	1.170	7.51
11	45.3	46.8	.848	.1375	1.180	7.27
12	46.45	48.0	.840	.142	1.191	7.03
13	47.6	49.2	.832	.147	1.202	6.80
14	48.8	50.4	.823	.152	1.215	6.57
15	50.0	51.65	.814	.158	1.228	6.34
16	51.2	52.9	.805	.164	1.242	6.12
17	52.4	54.2	.796	.170	1.256	5.90
18	53.7	55.5	.786	.176	1.272	5.68
19	55.0	56.8	.776	.183	1.289	5.46
20	56.3	58.15	.765	.191	1.307	5.24
21	57.6	59.5	.754	.199	1.326	5.03
22	59.0	60.95	.743	.208	1.346	4.81
23	60.4	62.4	.731	.217	1.368	4.60
24	61.8	63.85	.718	.228	1.393	4.39
25	63.2	65.3	.703	.240	1.422	4.18
26	64.7	66.85	.688	.252	1.454	3.97
27	66.2	68.4	.671	.266	1.490	3.76
28	67.7	69.95	.653	.283	1.531	3.54
29	69.2	71.5	.630	.303	1.587	3.30
30	70.7	73.1	.598	.334	1.672	2.99
30.5	71.5	73.9	.574	.356	1.742	2.80
31	72.3	74.7	.536	.392	1.866	2.55
31.25	72.7	75.2	.497	.422	2.012	2.37
31.35	72.9	75.35	.464	.464	2.155	2.155

TABLE 2 PHYSICAL PROPERTIES OF THE LIQUID AND THE SATURATED VAPOR OF CARBONIC ACID FROM 32 DEG. FAHR. TO THE CRITICAL TEMPERATURE 88.4 DEG. FAHR.

Temp. Deg. Fah	Pressure, Saturated Vapor		Density, Water at 39.2°F.=1		Wt. of One Cubic Ft. Pounds		Wt. of One Gallon Pounds		Volume of One Lb. Cubic Feet	
	Lbs. per Sq. In.	Atmospheres	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
32	504	34.3	.916	.096	57.2	5.99	7.64	.801	.0175	.167
33	511	34.8	.913	.098	57.0	6.10	7.62	.816	.0175	.164
34	519	35.3	.910	.100	56.8	6.21	7.59	.831	.0176	.161
35	526	35.8	.907	.101	56.6	6.32	7.57	.846	.0177	.158
36	534	36.3	.904	.103	56.4	6.44	7.54	.861	.0177	.155
37	542	36.9	.901	.105	56.2	6.55	7.52	.877	.0178	.152
38	549	37.4	.898	.107	56.1	6.67	7.49	.893	.0178	.149
39	557	37.9	.895	.109	55.9	6.80	7.47	.910	.0179	.147
40	565	38.5	.892	.111	55.7	6.92	7.44	.927	.0180	.144
41	573	39.0	.888	.113	55.5	7.05	7.42	.944	.0180	.142
42	581	39.5	.885	.115	55.3	7.18	7.39	.961	.0181	.139
43	589	40.1	.882	.117	55.1	7.31	7.36	.979	.0182	.136
44	598	40.7	.878	.120	54.8	7.45	7.33	.996	.0183	.134
45	606	41.2	.875	.122	54.6	7.59	7.30	1.015	.0183	.132
46	614	41.8	.871	.124	54.4	7.73	7.27	1.033	.0184	.129
47	623	42.4	.867	.126	54.1	7.87	7.24	1.05	.0185	.127
48	632	43.0	.863	.128	53.9	8.01	7.20	1.07	.0186	.125
49	641	43.6	.859	.131	53.6	8.16	7.17	1.09	.0187	.122
50	650	44.2	.855	.133	53.4	8.31	7.13	1.11	.0187	.120
51	659	44.8	.851	.136	53.1	8.46	7.10	1.13	.0188	.118
52	668	45.5	.847	.138	52.9	8.62	7.07	1.15	.0189	.116
53	677	46.1	.843	.141	52.6	8.79	7.03	1.17	.0190	.114
54	686	46.7	.838	.143	52.3	8.95	6.99	1.20	.0191	.112

55	696	47.4	.833	.146	52.0	9.12	6.95	1.22	.0192	.110
56	705	48.0	.829	.149	51.7	9.30	6.92	1.24	.0193	.108
57	715	48.6	.824	.152	51.4	9.48	6.88	1.27	.0194	.106
58	725	49.3	.819	.155	51.1	9.67	6.83	1.29	.0196	.104
59	735	50.0	.814	.158	50.8	9.86	6.79	1.32	.0197	.102
60	744	50.7	.809	.161	50.5	10.1	6.75	1.34	.0198	.0999
61	754	51.3	.804	.164	50.2	10.3	6.71	1.37	.0199	.0978
62	764	52.0	.799	.168	49.9	10.5	6.67	1.40	.0200	.0958
63	775	52.7	.794	.171	49.6	10.7	6.63	1.43	.0202	.0938
64	785	53.4	.788	.175	49.2	10.9	6.58	1.46	.0203	.0918
65	796	54.1	.783	.178	48.9	11.1	6.53	1.49	.0205	.0898
66	806	54.8	.777	.182	48.5	11.4	6.48	1.52	.0206	.0879
67	817	55.6	.771	.186	48.1	11.6	6.43	1.55	.0208	.0859
68	827	56.3	.765	.191	47.8	11.9	6.38	1.59	.0209	.0840
69	838	57.0	.759	.195	47.4	12.2	6.33	1.63	.0211	.0821
70	849	57.8	.753	.200	47.0	12.5	6.28	1.67	.0213	.0802
71	860	58.5	.747	.205	46.6	12.8	6.23	1.71	.0214	.0783
72	872	59.3	.740	.210	46.2	13.1	6.18	1.75	.0216	.0764
73	883	60.1	.733	.215	45.8	13.4	6.12	1.79	.0218	.0745
74	894	60.8	.726	.221	45.4	13.8	6.06	1.84	.0220	.0726
75	906	61.6	.719	.227	44.9	14.2	6.00	1.89	.0223	.0707
76	917	62.4	.711	.233	44.4	14.6	5.93	1.94	.0225	.0689
77	929	63.2	.703	.240	43.9	15.0	5.87	2.00	.0228	.0670
78	941	64.0	.695	.246	43.4	15.4	5.80	2.05	.0231	.0651
79	953	64.9	.686	.253	42.8	15.8	5.72	2.11	.0234	.0633
80	965	65.7	.677	.261	42.2	16.3	5.65	2.18	.0237	.0614
81	977	66.5	.667	.269	41.6	16.8	5.57	2.25	.0240	.0595
82	989	67.3	.657	.278	41.0	17.4	5.48	2.32	.0244	.0575
83	1002	68.2	.646	.288	40.3	18.0	5.39	2.40	.0248	.0555
84	1015	69.0	.633	.300	39.5	18.7	5.28	2.50	.0253	.0533
85	1027	69.9	.618	.315	38.6	19.7	5.16	2.63	.0259	.0508
86	1039	70.7	.598	.334	37.3	20.9	4.99	2.79	.0268	.0479
87	1052	71.6	.571	.360	35.6	22.5	4.76	3.00	.0281	.0445
88	1065	72.5	.523	.404	32.7	25.2	4.36	3.37	.0308	.0397
88.4	1071	72.9	.464	.464	29.0	29.0	3.87	3.87	.0345	.0345

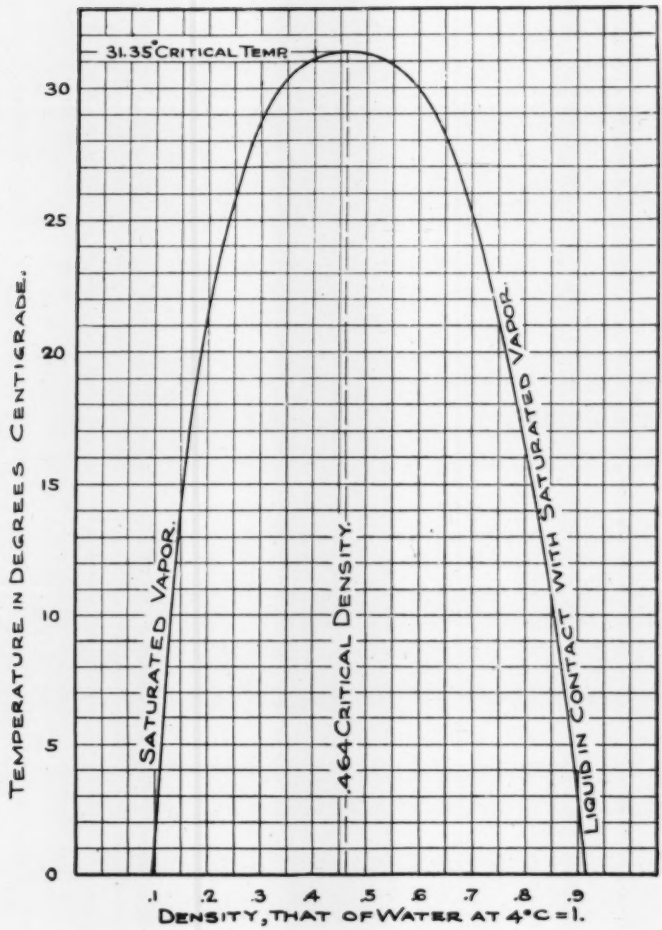

FIG. 1 CURVE SHOWING THE RELATION OF DENSITY TO TEMPERATURE OF CARBONIC ACID FOR TEMPERATURES LESS THAN CRITICAL TEMPERATURE

TABLE 3 PRESSURE EXERTED BY CARBONIC ACID ON THE WALLS OF THE CONTAINING VESSEL, IN POUNDS PER SQUARE INCH

PORTION OF TABLE ABOVE *AB* IS FOR COMBINED DENSITY OF LIQUID AND OVERLYING VAPOR

Density, Water at 4°C=1	Temperature, Degrees Centigrade.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
.50	504	650	827	1039	1305	1585	1870	2155	2445	2730	3020
.51	504	650	827	1039	1310	1600	1895	2190	2485	2780	3080
.52	504	650	827	1039	1320	1615	1915	2220	2525	2830	3140
.53	504	650	827	1039	1330	1630	1940	2255	2570	2880	3205
.54	504	650	827	1039	1335	1650	1970	2295	2615	2940	3270
.55	504	650	827	1039	1345	1670	1995	2330	2665	3000	3340
.56	504	650	827	1039	1355	1690	2025	2370	2715	3060	3410
.57	504	650	827	1039	1365	1710	2055	2410	2770	3125	3490
.58	504	650	827	1039	1375	1730	2090	2455	2825	3195	3570
.59	504	650	827	1039	1385	1755	2125	2505	2885	3270	3655
.60	504	650	827	1040	1400	1780	2160	2555	2945	3345	3745
.61	504	650	827	1045	1415	1805	2200	2605	3010	3420	3835
.62	504	650	827	1045	1430	1830	2240	2655	3075	3500	3925
.63	504	650	827	1050	1445	1860	2285	2710	3145	3580	4020
64	504	650	827	1060	1465	1895	2330	2770	3215	3665	4120
.65	504	650	827	1065	1490	1930	2375	2835	3295	3755	4225
.66	504	650	827	1075	1515	1965	2430	2900	3375	3850	4335
.67	504	650	827	1090	1540	2005	2485	2970	3465	3955	4455
.68	504	650	827	1105	1570	2050	2545	3050	3555	4065	4580
.69	504	650	827	1125	1600	2100	2615	3130	3655	4180	4710
.70	504	650	827	1150	1635	2155	2685	3220	3765	4305	4850
.71	504	650	827	1175	1680	2215	2760	3315	3875	4435	5000
.72	504	650	827	1205	1730	2280	2845	3420	3995	4575	5155
73	504	650	827	1245	1785	2355	2940	3530	4125	4720	5315
.74	504	650	827	1285	1845	2435	3040	3645	4260	4870	5490
.75	504	650	827	1330	1915	2520	3145	3770	4405	5035	5670
.76	504	650	827	1380	1985	2610	3255	3905	4560	5210	5865
.77	504	650	845	1440	2060	2710	3380	4050	4720	5390	6065
.78	504	650	885	1505	2150	2815	3510	4200	4895	5585	6275
79	504	650	935	1570	2240	2930	3650	4365	5080	5790	6500
.80	504	650	985	1645	2340	3060	3800	4535	5275	6010	6740
.81	504	650	1045	1730	2450	3195	3960	4720	5485	6240	7000
.82	504	650	1110	1820	2570	3345	4130	4920	5705	6490	7265
.83	504	650	1180	1925	2700	3505	4315	5130	5940	6750	7555
.84	504	650	1260	2035	2845	3670	4510	5355	6195	7025	7855
.85	504	650	1355	2160	3005	3855	4720	5595	6460	7320	8175
.86	504	683	1460	2300	3175	4055	4950	5845	6745	7630	8520
.87	504	765	1575	2455	3360	4270	5200	6120	7040	7960	8885
.88	504	855	1705	2620	3565	4510	5465	6415	7365	8310	9265
.89	504	960	1850	2800	3785	4765	5740	6720	7700	8680	9660
.90	504	1080	2015	3005	4020	5030	6045	7055	8060	9070	10070
.91	504	1215	2195	3230	4285	5330	6370	7405	8440	9470	10510
.92	530	1360	2395	3480	4560	5630	6700	7770	8840	9910	10990
.93	620	1525	2615	3750	4850	5950	7060	8160	9270	10370	11480
.94	725	1715	2860	4030	5160	6290	7430	8560	9710	10840	11980
.95	855	1935	3125	4325	5490	6650	7820	9000	10180	11350	12500
.96	1010	2175	3410	4640	5840	7030	8240	9460	10690	11880	13050
.97	1200	2445	3715	4975	6210	7440	8680	9950	11230	12440	13620
.98	1435	2745	4050	5330	6600	7880	9180	10470	11780	13000	14190
.99	1700	3065	4410	5720	7030	8340	9710	11040	12350	13570	14780
1.00	2010	3415	4790	6140	7500	8850	10270	11650	12960	14160	15370

TABLE 4 PRESSURE EXERTED BY CARBONIC ACID ON THE WALLS OF THE CONTAINING VESSEL, IN POUNDS PER SQUARE INCH[1]

Density, Water at 39.2°F=1	Temperature in Degrees Fahrenheit.								
	32°	40°	50°	60°	70°	80°	90°	100°	110°
.50	504	565	650	744	849	965	1095	1245	1395
.51	504	565	650	744	849	965	1100	1250	1405
.52	504	565	650	744	849	965	1100	1250	1405
.53	504	565	650	744	849	965	1100	1255	1415
.54	504	565	650	744	849	965	1100	1260	1425
.55	504	565	650	744	849	965	1105	1265	1440
.56	504	565	650	744	849	965	1105	1270	1450
.57	504	565	650	744	849	965	1105	1280	1465
.58	504	565	650	744	849	965	1110	1290	1475
.59	504	565	650	744	849	965	1110	1300	1490
.60	504	565	650	744	849	965	1115	1310	1505
.61	504	565	650	744	849	965	1115	1320	1520
.62	504	565	650	744	849	965	1120	1330	1540
.63	504	565	650	744	849	965	1130	1340	1560
.64	504	565	650	744	849	965	1140	1355	1580
							1150	1375	1605
.65	504	565	650	744	849	965	1160	1395	1630
.66	504	565	650	744	849	965	1175	1415	1660
.67	504	565	650	744	849	965	1190	1440	1690
.68	504	565	650	744	849	972	1205	1465	1725
.69	504	565	650	744	849	990	1230	1495	1765
.70	504	565	650	744	849	1005	1255	1530	1810
.71	504	565	650	744	849	1025	1285	1570	1855
.72	504	565	650	744	849	1050	1320	1610	1910
.73	504	565	650	744	849	1080	1360	1660	1970
.74	504	565	650	744	849	1110	1405	1720	2035
.75	504	565	650	744	849	1145	1460	1785	2110
.76	504	565	650	744	870	1190	1515	1850	2190
.77	504	565	650	744	910	1240	1575	1925	2275
.78	504	565	650	744	955	1295	1645	2005	2370
.79	504	565	650	744	1005	1355	1715	2090	2470
.80	504	565	650	744	1060	1425	1795	2185	2575
.81	504	565	650	750	1120	1500	1885	2290	2695
.82	504	565	650	800	1190	1585	1985	2405	2825
.83	504	565	650	860	1260	1675	2095	2530	2965
.84	504	565	650	935	1345	1780	2215	2665	3115
.85	504	565	650	1020	1445	1895	2345	2815	3285
.86	504	565	685	1110	1550	2020	2490	2980	3465
.87	504	565	765	1210	1665	2155	2650	3160	3665
.88	504	565	855	1325	1800	2310	2825	3360	3880
.89	504	565	960	1450	1950	2485	3020	3565	4110
.90	504	655	1080	1595	2120	2675	3235	3800	4355
.91	A 504	765	1215	1755	2305	2880	3470	4050	4625
.92	530	880	1360	1925	2505	3115	3720	4320	4910
.93	620	1005	1525	2120	2740	3375	3995	4610	
.94	725	1145	1715	2340	2990	3645	4280	4920	
.95	855	1320	1935	2590	3255	3935	4585		
.96	1010	1515	2175	2860	3545	4240	4910		
.97	1200	1740	2445	3150	3850	4565			
.98	1435	2005	2745	3480	4195	4915			
.99	1700	2305	3065	3825	4555				
1.00	2010	2635	3415	4200	4940				

[1] The density here given is the combined density of the liquid and the overlying vapor for portion of table lying above *AB*, and is the same as the proportion of filling in pounds of carbonic acid per pound of water capacity.

TABLE 4—CONTINUED

Temperature in Degrees Fahrenheit.									
120°	130°	140°	150°	160°	170°	180°	190°	200°	212°
1550	1710	1870	2030	2185	2345	2505	2665	2825	3020
1565	1730	1895	2055	2220	2385	2550	2715	2880	3080
1580	1750	1915	2085	2255	2425	2595	2765	2930	3140
1600	1770	1940	2115	2290	2465	2640	2815	2990	3205
1615	1790	1970	2145	2325	2505	2685	2870	3050	3270
1630	1810	1995	2180	2365	2550	2735	2925	3110	3340
1650	1835	2025	2215	2405	2600	2790	2980	3175	3410
1670	1860	2055	2255	2450	2650	2845	3045	3245	3490
1690	1885	2090	2295	2495	2705	2905	3115	3320	3570
1710	1915	2125	2335	2545	2760	2970	3185	3395	3655
1735	1945	2160	2380	2595	2815	3035	3255	3475	3745
1760	1975	2200	2425	2645	2875	3100	3330	3555	3835
1785	2010	2240	2475	2700	2940	3170	3405	3640	3925
1815	2045	2285	2525	2760	3005	3240	3485	3725	4020
1845	2080	2330	2575	2820	3070	3315	3570	3815	4120
1875	2120	2375	2630	2885	3140	3395	3655	3910	4225
1910	2165	2430	2690	2950	3215	3480	3750	4010	4335
1950	2210	2485	2755	3025	3300	3570	3850	4120	4455
1995	2265	2545	2825	3105	3390	3670	3955	4235	4580
2040	2325	2615	2900	3190	3485	3775	4070	4355	4710
2095	2385	2685	2985	3280	3585	3885	4190	4485	4850
2150	2455	2760	3070	3375	3690	4000	4315	4620	5000
2215	2530	2845	3165	3480	3800	4125	4450	4765	
2290	2610	2940	3265	3595	3925	4260	4590	4915	
2365	2700	3040	3375	3715	4055	4400	4740		
2450	2790	3145	3495	3845	4195	4545	4895		
2535	2890	3255	3620	3980	4340	4700			
2635	3000	3380	3755	4120	4495	4865			
2740	3120	3510	3895	4275	4665				
2850	3245	3650	4050	4440	4840				
2975	3385	3800	4210	4615					
3110	3530	3960	4390	4800					
3255	3685	4130	4575	5000					
3410	3855	4315	4775						
3575	4040	4510	4985						
3760	4240	4720							
3960	4450	4950							
4175	4680								
4410	4935								
4655									
4915									

TABLE 5 PORTION OF THE CYLINDER VOLUME THAT IS OCCUPIED BY THE LIQUID FOR DIFFERENT COMBINED DENSITIES OF THE LIQUID AND SATURATED VAPOR OF CARBONIC ACID

Combined Density, That of Water=1	Temperature in Degrees Fahrenheit.										
	32°	40°	50°	60°	70°	75°	80°	82°	84°	86°	88°
.50	.493	.498	.508	.523	.543	.555	.575	.587	.601	.629	.807
.51	.505	.511	.522	.539	.561	.575	.599	.614	.631	.667	.891
.52	.517	.524	.536	.554	.579	.596	.623	.640	.661	.705	.975
.53	.529	.536	.550	.569	.597	.616	.647	.667	.691	.742	1.
.54	.541	.549	.564	.585	.615	.636	.671	.693	.721	.780	1.
.55	.554	.562	.578	.600	.633	.657	.695	720	751	.818	1.
.56	.566	.575	.591	.616	651	.677	719	.746	.781	.856	1.
.57	.578	.588	.605	.631	.669	.697	743	.772	.811	.894	1.
.58	.590	.601	.619	.647	.687	.717	767	.799	.841	.932	1.
.59	.602	.613	.633	.662	.705	.738	.791	.825	.871	.970	1
.60	.615	.626	.647	.677	723	.758	.815	.852	.901	1.	1.
.61	.627	.639	.661	.693	.741	.778	.839	.878	.931	1.	1.
.62	.639	.652	.675	708	.759	.799	.863	.905	.961	1	1.
.63	.651	.665	.688	724	.778	.819	.887	.931	.991	1.	1.
.64	.663	.677	.702	.739	.796	.839	.911	.958	1.	1.	1
.65	.676	.690	716	.755	.814	.860	.935	.984	1.	1	1
.66	.688	.703	730	.770	.832	.880	.959	1.	1	1	1.
.67	700	716	.744	.785	.850	.900	.983	1.	1.	1.	1.
.68	712	729	758	.801	.868	.921	1.	1.	1.	1	1.
.69	724	741	.771	.816	.886	.941	1.	1.	1.	1	1.
.70	737	754	785	832	904	.961	1.	1.	1	1.	1.
.71	749	767	799	.847	.922	.982	1.	1.	1.	1	1.
.72	.761	.780	.813	.863	.940	1.	1.	1.	1.	1.	1.
.73	773	793	.827	.878	.958	1.	1	1	1	1	1.
.74	785	.805	.841	.894	.976	1.	1.	1.	1.	1	1.
.75	798	.818	855	.909	.995	1.	1.	1.	1.	1.	1
.76	.810	.831	.868	.924	1.	1.	1.	1.	1.	1.	1.
.77	.822	.844	.882	.940	1.	1.	1.	1.	1.	1.	1.
.78	.834	.857	.896	.955	1.	1.	1.	1.	1.	1.	1.
.79	.846	.869	.910	.971	1.	1.	1.	1.	1.	1.	1.
.80	.859	.882	.924	.986	1.	1.	1.	1.	1.	1.	1
.81	.871	.895	.938	1.	1.	1.	1.	1.	1.	1.	1.
.82	883	.908	.952	1.	1.	1.	1.	1.	1.	1.	1.
.83	.895	.921	.965	1.	1.	1.	1.	1.	1.	1.	1.
.84	.907	.933	.979	1.	1.	1.	1.	1.	1.	1.	1.
.85	.920	.946	.993	1.	1.	1.	1.	1.	1.	1.	1.
90	.980	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
95	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
1.00	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.

TABLE 5—CONTINUED

Temperature in Degrees Centigrade.										
0°	5°	10°	15°	20°	22°	24°	26°	28°	30°	31°
.493	.499	.508	.521	.538	.546	.555	.569	.588	.629	.750
.505	.512	.522	.537	.556	.564	.576	.592	.615	.667	.819
.517	.525	.536	.552	.573	.583	.596	.615	.642	.705	.889
.529	.538	.550	.567	.591	.602	.616	.638	.668	.742	.958
.541	.551	.564	.582	.608	.621	.637	.661	.695	.780	1.
.554	.564	.578	.598	.625	.639	.657	.684	.722	.818	1
.566	577	.591	.613	.643	.658	.678	.706	.749	.856	1.
.578	.590	.605	.628	.660	.677	.698	.729	.776	.894	1.
.590	.603	.619	.643	.678	.695	.718	.752	.803	.932	1.
602	.615	.633	.659	.695	714	.739	.775	.830	.970	1.
.615	.628	.647	.674	713	.733	.759	.798	.857	1.	1.
627	.641	.661	.689	730	.751	780	.821	.884	1.	1.
.639	.654	.675	.704	.747	.770	.800	.844	.911	1.	1.
.651	.667	.688	.720	.765	.789	.820	.867	.938	1.	1.
.663	.680	.702	.735	.782	.807	.841	.890	.965	1.	1.
.676	.693	.716	.750	.800	.826	.861	.913	.992	1.	1.
.688	.706	730	.765	.817	.845	.882	.936	1.	1.	1.
.700	.719	.744	.780	.834	.864	.902	.959	1.	1.	1.
.712	.732	.758	.796	.852	.882	.922	.982	1.	1.	1.
.724	.745	.771	.811	.869	.901	943	1.	1.	1.	1.
.737	.757	.785	.826	.887	920	963	1	1.	1.	1.
749	.770	.799	.841	.904	.938	984	1.	1.	1.	1.
.761	.783	.813	.857	.922	.957	1.	1.	1.	1.	1.
.773	.796	.827	.872	.939	.976	1.	1.	1.	1.	1.
785	.809	.841	.887	.956	.994	1.	1.	1.	1.	1.
.798	.822	.855	.902	.974	1.	1.	1.	1.	1.	1.
.810	.835	.868	.918	.991	1.	1.	1.	1.	1.	1.
.822	.848	.882	.933	1.	1.	1.	1.	1.	1.	1.
.834	.861	.896	.948	1.	1.	1.	1.	1.	1.	1.
.846	.874	.910	.963	1.	1.	1.	1.	1.	1.	1.
.859	.886	.924	.979	1.	1.	1.	1.	1.	1.	1.
.871	.899	.938	.994	1.	1.	1.	1.	1.	1.	1.
.883	.912	.952	1.	1.	1.	1.	1.	1.	1.	1.
.895	.925	.965	1.	1.	1.	1.	1.	1.	1.	1.
.907	.938	.979	1.	1.	1.	1.	1.	1.	1.	1.
.920	.951	.993	1.	1.	1.	1.	1	1.	1.	1.
.980	1.	1.	1.	1.	1.	1	1.	1.	1.	1.
1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.

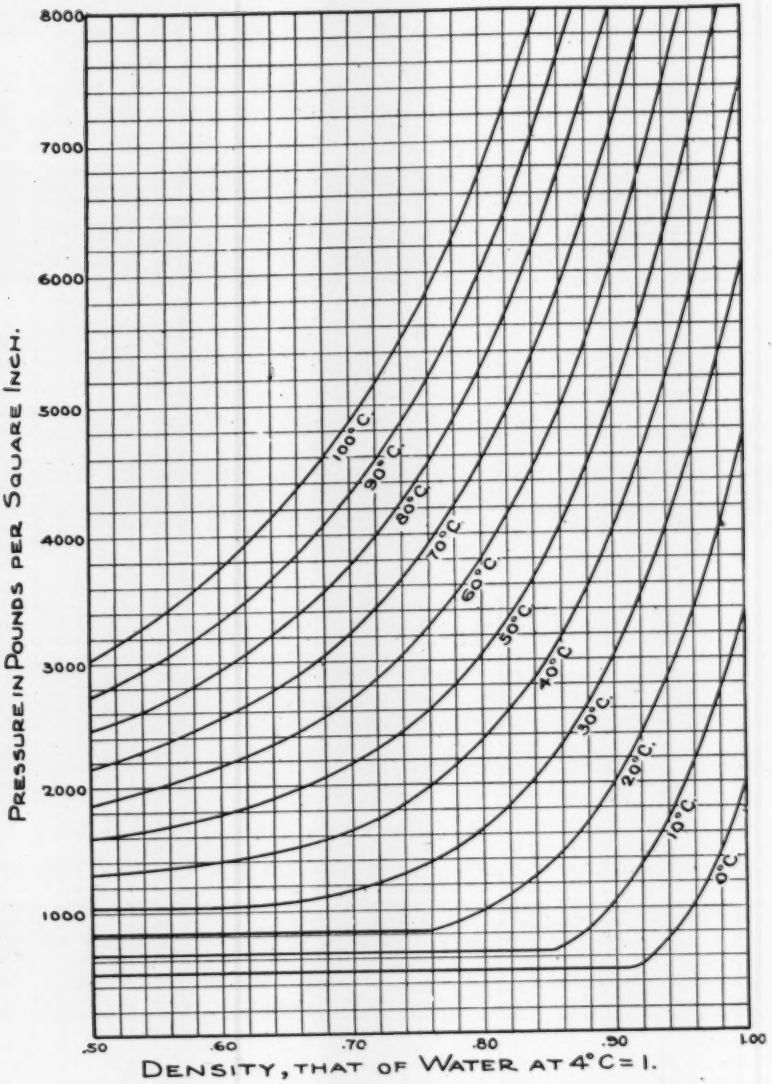

FIG. 2 PRESSURE EXERTED BY CARBONIC ACID ON THE WALLS OF THE CONTAINING VESSEL, IN POUNDS PER SQUARE INCH

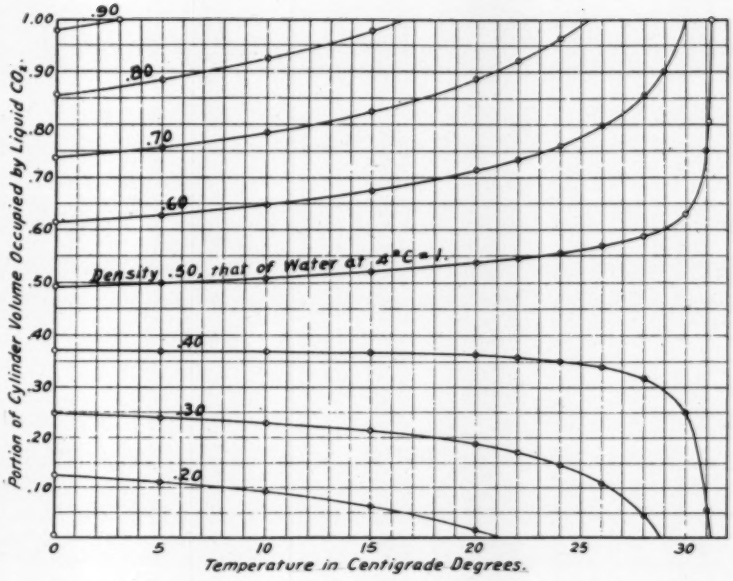

FIG. 3 SHOWING THAT FOR COMBINED DENSITIES GREATER THAN THE CRITICAL DENSITY AN INCREASE IN TEMPERATURE IS ATTENDED BY AN INCREASE IN THE LIQUID VOLUME OF CARBONIC ACID CONTAINED IN A CYLINDER, WHILE FOR DENSITIES LESS THAN THE CRITICAL THE LAW IS REVERSED, INCREASE IN TEMPERATURE BEING ATTENDED BY DECREASE IN LIQUID VOLUME

PART 2 ECONOMIC STORAGE FOR TRANSPORTATION

Experiments on Carbonic Acid when under the Conditions of Commercial Storage for Transportation

73 All of the tables in Part 1 of this paper are based upon careful laboratory experiments conducted upon small quantities of purified and dried carbon dioxid. Those who may desire to use these scientific tables for either the design of new carbonic acid cylinders, or for the investigation of the safety of cylinders that are now in use, should have a clear understanding of what modifications, if any, should be made in these tables, when applying them to such purposes.

74 Commercial carbonic acid is generally saturated with water vapor, and will also be found to contain some air. Physicists apparently have not determined the pressures resulting from mixtures of gases and vapors under the conditions of the commercial storage of carbonic acid. The author, therefore, conducted experiments on commercial carbonic acid when under the precise conditions of storage for transportation. He has thus verified the scientific tables contained in Part 1, in so far as they bear directly upon the design of carbonic acid cylinders.

75 This experimental investigation was carried out in the mechanical laboratory of the Engineering School of the University of Pittsburg, by Frank P. Kramer, assisted by William M. Cooper, the whole being conducted under the immediate direction of the author.

GENERAL SCHEME OF EXPERIMENTS

76 The experiments were conducted according to the following general scheme: (1) a carbonic acid cylinder charged in the ordinary commercial way, was placed in a water jacket, which was provided with means for maintaining a constant known temperature; (2) samples of the carbonic acid were drawn off and analyzed for percentage of gaseous residue, or air content; (3) a pressure gage was then attached to the cylinder and the pressure determined corresponding to the known temperature; (4) the cylinder was then removed from the water jacket, dried externally, and weighed on an equal-arm balance; and (5) the cylinder was returned to the water jacket, where a certain definite quantity of acid was slowly discharged, and the

experiment was then repeated until the cylinder became fully discharged, the final weight obtained being that of the empty cylinder.

WATER JACKET

77 This was perhaps the most important piece of apparatus especially constructed for these experiments. It consisted as shown in Fig. 4, of a heavy seamless steel cup, which was protected from external radiation by means of a non-conducting covering. This piece of apparatus was designed with particular care with reference to keeping all parts of the carbonic acid cylinder under test at a constant predetermined temperature. Heat could be gradually imparted to the water jacket by means of the gas burner shown at the bottom, or heat could be gradually withdrawn by means of a cool water supply, not shown, at the top, the surplus water passing away automatically by means of an overflow. A very important feature was the longitudinal division of the water jacket into two parts, by which means the small propeller shown could produce a positive and rapid circulation of the water throughout the length of the jacket. By these means no difficulty whatever was had in maintaining in all parts of the water jacket a predetermined temperature, within 0.1 deg. fahr.

78 The thickness of the wall of the seamless steel cup constituting this water jacket was made sufficient to protect the attendants from injury in case the carbonic acid cylinder under test should accidentally rupture.

SCHEME OF ANALYSIS FOR AIR CONTENT

79 The maturing of a satisfactory scheme for obtaining both readily and accurately the gaseous residue in the commercial carbonic acid, under the conditions of storage for transportation, was at first a source of considerable anxiety to the author. The following scheme, however, proved to be entirely satisfactory.

SELECTION OF A SAMPLE

80 The selection of a representative sample of the gas from a commercial cylinder presented the first difficulty. As fully explained in Part 1 of this paper, the contents of a carbonic acid cylinder will

be found to consist, at ordinary factory or laboratory temperatures, of a liquid portion overlaid by the vapor of carbonic acid. It is known of course in a general way that the air contained in the cylinder is unequally distributed within the liquid and the overlying vapor.

81 After due consideration of the matter it was decided that the best practical means for obtaining a representative sample of gas from a commercial cylinder would be to place the cylinder in a water jacket and elevate its temperature well above the critical temperature of the acid, thus converting the entire contents of the cylinder into a homogeneous gaseous mixture. This method for obtaining a representative sample of commercial carbonic acid has been thoroughly tested under the direction of the author, and has been found to be strictly reliable.

82 The truth of the above statement becomes apparent from an inspection of Table 6, which shows the results obtained by taking samples from the top of a commercial carbonic acid cylinder, at regular intervals while the cylinder was being slowly discharged, first, when the carbonic acid was above its critical temperature of 88.4 deg. fahr., and second, when below this temperature. This table shows that while the carbonic acid was being discharged at 110 deg. fahr. the successive analyses gave a constancy of gaseous residue within one-tenth of one per cent, and that while being discharged at 50 deg. fahr. the analyses gave a gaseous residue that varied from 8.2 to 0.2 per cent. That is to say, while the former gave constant results within the limit of accuracy of the apparatus used, the latter showed an extreme variation of about 4000 per cent.

SAMPLING CYLINDER FOR GAS ANALYSIS

83 While sampling commercial carbonic acid cylinders for gas analysis there should be kept in mind the following: First, that while below the critical temperature of 31.4 deg. cent., or 88.4 deg. fahr., the contents of a carbonic acid cylinder, as fully explained elsewhere in this paper, consists of a liquid portion overlaid by the vapor of carbonic acid, just as in a steam boiler the water is overlaid by steam; second, that the air is unequally distributed in the liquid carbonic acid and in its overlying vapor, thus rendering it impracticable to secure a representative sample for analysis from a cylinder when the contents are below the critical temperature of the carbonic

acid; third, that when above the critical temperature, if the cylinder has stood sufficiently long for complete diffusion, the contents of a commercial carbonic acid cylinder will consist of a homogeneous mixture of gaseous carbon dioxid with any impurities that are present in the gaseous or vaporous state, such as air and water vapor.

84 It is apparent then, from what has been given, especially from Table 6, that the only really reliable method for sampling a commercial carbonic acid cylinder is, first, to bring its temperature well above the critical temperature of carbon dioxid, or to say 100 deg. fahr., and then hold the cylinder at such temperature for a sufficient length of time for the complete diffusion of any gaseous or vaporous impurities that may be present before drawing off a sample for analysis.

85 Water in the liquid form and liquid lubricants coming over from the compressors, if these be present, will be found collected at the bottom of the cylinder and should be dealt with accordingly.

PRESSURE REGULATOR

86 The pressure regulator shown in Fig. 4 was devised to overcome the difficulty attendant upon supplying gas, when stored under pressures varying from 1000 to 2000 or more lb. per square inch, to a burette, where the pressure is atmospheric. It is clearly impracticable to supply the gas directly from the cylinder valve to the burette without the use of some sort of pressure regulator, because no nice adjustment of flow can be effected by means of the regular cylinder valve, because of the violent spitting action due to "freezing" in the valve.

87 The regulator used, as shown in the figure, consisted of placing a tee in the tube leading from the cylinder valve to the burette, the side branch of the tee terminating in an open glass tube hanging vertically in a bath of water. By this simple device the gas supply to the burette was kept at a constant pressure, all variable excess of gas escaping automatically from the lower end of the vertical glass tube. This exceedingly simple regulator made it possible to fill the burette with the greatest ease and prevented any possibility of accident to the burette while being filled.

BURETTE FOR THE GAS ANALYSIS

88 The burette for the gas analysis consisted of a modified form of Bunte's apparatus, adapted to making rapid determinations of gaseous residues to the nearest 0.1 per cent. The regulator and burette were arranged and manipulated so that the sample of carbonic acid for analysis nowhere bubbled up through water, but was made to enter the burette from the top by means of water displacement, the absorption being effected in the usual way by means of potassium hydroxid. This apparatus gave results that were uniformly consistent within one-tenth of one per cent of gaseous residue.

EFFECTS OF GASEOUS IMPURITIES UPON THE PRESSURES EXERTED

89 These are shown very clearly in Fig. 6. This chart is for a temperature of 120 deg. fahr., and shows the different pressures corresponding to combined densities ranging from 0.5 to 0.7. Curve A is plotted from the values given in Table 4, and shows the relation of pressure to temperature and density for pure carbon dioxid. Curve B is plotted from experiments on commercial carbonic acid contained in commercial cylinders, when the carbonic acid is saturated with water vapor and the gaseous residues or air content is 0.7 per cent. Curve C, ditto, when the gaseous residue or air content is 1.7 per cent.

90 For the most economic conditions of commercial storage and transportation, then, 1 per cent of air content corresponds to an increase in the fluid pressure of about 60 lb. per square inch.

PRESSURE GAGE

91 The gage used in connection with these experiments was a Shaw differential-piston mercury-gage, having a capacity of 3000 lb. per square inch. The scale of this gage was calibrated by means of a dead-weight tester, having a capacity of 1000 lb., the scale being pointed at 500, 750 and 1000 lb., and these in turn duplicated up to 3000 lb. All pressures recorded in this paper as obtained from carbonic acid cylinders were corrected in accordance with this calibration.

92 The dead-weight tester used in calibrating the pressure gage was examined by calipering the plunger and by weighing the individual weights used and was found to be substantially correct.

WEIGHING CYLINDERS AND ACID

93 The commercial carbonic acid experimented with was contained in steel cylinders that were nominally 5 in. inside diameter and 50½ in. long. These cylinders were made expressly for these experiments of ductile steel. The cylinders were seamless and were constructed of sufficient thickness of wall to secure about double the safety of the ordinary commercial cylinder of the same capacity. This was deemed necessary as a proper safeguard in view of the fact that these cylinders were to be subjected to the highest pressure conditions reached by commercial charged cylinders. In order, therefore, to obtain correct weights of the acid experimented with it was necessary to make accurate gross weighings in the neighborhood of from 150 to 175 lb.

94 It was thought at first that the weighings could be made on a platform scale, built by a well-known scale firm for laboratory purposes, having a capacity of 300 lb. and capable of being read to 0.01 lb. In an attempt to calibrate this platform scale, before being put into use, it was immediately discovered that it was incapable of giving accurate readings. This became apparent when a standard ten pound weight, when placed upon its platform, gave readings which varied by as much as 43 times the smallest reading of the beam, which variation appeared to be caused by a change in the leverage ratio which was due to a shifting of the parts underneath the platform.

95 After due consideration of the matter it was decided to weigh the charged and empty carbonic acid cylinders in the manner illustrated in Fig. 5, the inherent inaccuracies of the platform scale rendering its use inadmissible for scientific work where, as in this case, the gross weights are many times as great as the corresponding net weights to be determined. As shown in the figure the weighings were made on an equal-arm balance, especially constructed of sufficient capacity for the purpose, and provided with suitable means for suspending the carbonic acid cylinder from the knife edge of one end, while the usual form of scale pan was suspended from the knife edge of the other end. All weighings were recorded to the nearest .01 lb. only, as this was deemed quite exact enough for the present investigation, although weighings could of course have been made with much greater precision.

WATER CAPACITY OF CYLINDER

96 The water capacities of the cylinders used were obtained as follows: first, the cylinder, while being suspended in a vertical position, was filled with distilled water, after which heat was applied until the water boiled, thus expelling the air in solution; second, the cylinder was then placed in the water jacket shown in Fig. 4 and cooled to a temperature approximating that of the laboratory hydrant water; third, distilled water, separately boiled and cooled in a flask, was poured into the cylinder to make up the deficiency due to shrinkage of water volume while the cylinder was being cooled; fourth, the cylinder was then removed from the water jacket, surface dried, and weighed in the manner shown in Fig. 5; and, fifth, the cylinder was then emptied, dried internally, reweighed, and the water capacity obtained by taking the difference of cylinder weights thus obtained; the final reduction to standard conditions being made by means of Castell Evans Physico-Chemical Tables, 1902 edition.

97 An investigation was made to discover what error in water capacity would result from the use of ordinary Pittsburg hydrant water without any corrections whatever being made for dissolved air and other impurities, reduction to vacuo and maximum density, etc. The results of this investigation showed that for commercial purposes it is not necessary to observe these refinements, when obtaining the water capacity of a cylinder, since the errors resulting from the use, without any corrections whatever, of ordinary hydrant water will not exceed those due to the ordinary inaccuracies of commercial operations.

98 For commercial cylinders, then, the proper weight of carbonic acid to be charged, as based upon the tables contained in this paper, may be had as follows: first, obtain the water capacity of the cylinder by subtracting its weight when empty from its weight when filled with ordinary clear stream or hydrant water; and, second, multiply the resulting water capacity in pounds, by the mean density of the carbonic acid, Table 7, corresponding to the greatest temperature to which the charged cylinder is to be subjected.

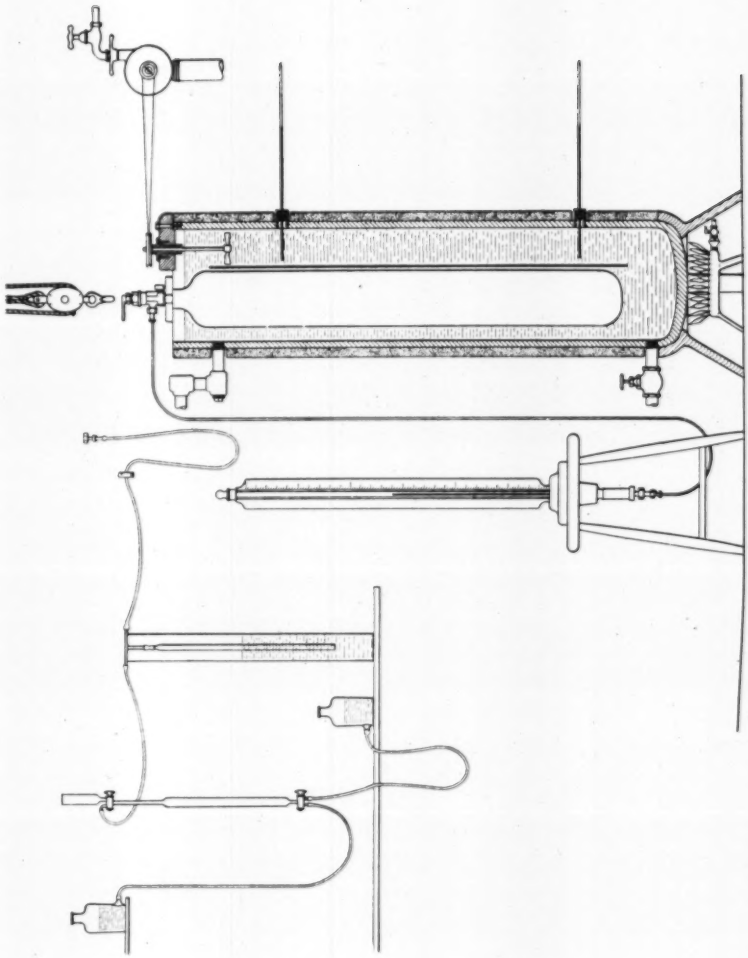

FIG. 4 APPARATUS USED IN EXPERIMENTS ON CARBONIC ACID UNDER THE CONDITIONS OF COMMERCIAL STORAGE FOR TRANSPORTATION

TABLE 6 SHOWING CONSTANCY OF AIR CONTENT OF COMMERCIAL CARBONIC ACID WHEN SAMPLES FOR ANALYSIS ARE DRAWN OFF AT 110 DEG. FAHR. COMPARED WITH THE VARIABLE AIR CONTENT OBTAINED FROM SAMPLES DRAWN OFF AT 50 DEG. FAHR., THE FORMER ABOVE AND THE LATTER BELOW THE CRITICAL TEMPERATURE OF 88.4 DEG. FAHR.[1]

First Filling of Cylinder "B" Slowly Discharged at Temperature of 110°F.			Second Filling of Cylinder "B" Slowly Discharged at Temperature of 50°F.		
Weight of CO_2 Pounds	Density of CO_2 Water = 1.	Air in CO_2 Per cent.	Weight of CO_2 Pounds.	Density of CO_2 Water = 1.	Air in CO_2 Per cent.
22.97	.690	.75	22¼	.67	8.2
19.92	.599	.75	21½	.65	6.8
19.64	.590	.8	20½	.62	5.8
18.97	.570	.8	19	.57	4.5
17.98	.540	8	18¼	.55	3.3
17.10	.514	.8	17¼	.52	2.5
15.90	.478	.75	16	.48	1.9
14.64	.440	.8	15	.45	1.5
13.28	.399	.8	14	.42	1.1
12.02	.361	.8	12½	.38	.8
10.64	.320	.8	11½	.35	.6
9.28	.279	.75	10½	.32	.5
8.07	243	.8	9¼	.28	.4
6.38	192	.8	7¼	.22	.3
5.45	164	75	4¾	.14	.2
4.49	135	.8			
3.67	.110	.8			
2.34	.071	.8			
1.29	.039	.8			
0.00	.000	.75			

[1] No determination was made for the actual air content for the second filling of cylinder B. When making comparison it should not therefore be assumed to be the same as for the first filling.

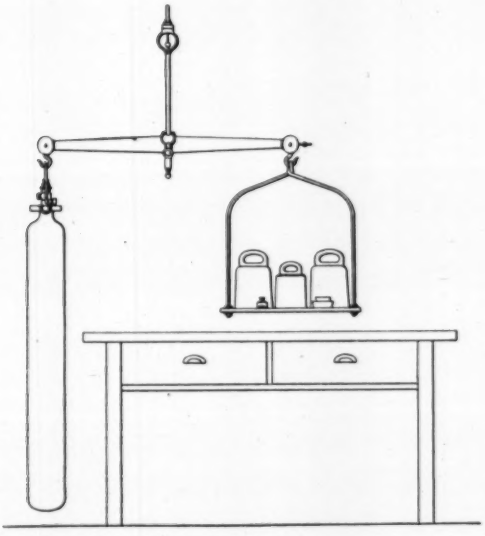

FIG. 5 METHOD OF WEIGHING THE CARBONIC ACID CYLINDERS

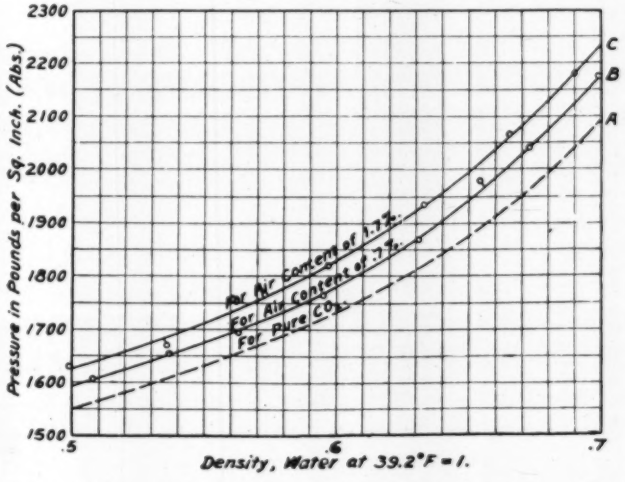

FIG. 6 SHOWING FOR A TEMPERATURE OF 120 DEG. FAHR. THE DIFFERENT PRESSURES CORRESPONDING TO COMBINED DENSITIES RANGING FROM .50 TO 0.7

CURVE A IS PLOTTED FROM THE VALUES GIVEN IN TABLE 4, AND SHOWS THE RELATION OF PRESSURE TO TEMPERATURE AND DENSITY FOR PURE CARBON DIOXID. CURVE B IS PLOTTED FROM EXPERIMENTS ON COMMERCIAL CARBONIC ACID CONTAINED IN COMMERCIAL CYLINDERS, WHEN THE GASEOUS RESIDUE OR AIR CONTENT IS 0.7 PER CENT. CURVE C, DITTO, WHEN THE GASEOUS RESIDUE OR AIR CONTENT IS 1.7 PER CENT. FOR THE MOST ECONOMIC CONDITIONS OF STORAGE, THEN, 1 PER CENT OF AIR CONTENT CORRESPONDS TO AN INCREASE IN THE FLUID PRESSURE OF 60 LB. PER SQUARE INCH

PART 3 DESIGN OF CARBONIC ACID CYLINDERS

99 The foregoing tables of the physical properties of carbonic acid are of sufficient scope to permit of a full inquiry into the economics of carbonic acid storage and transportation. It was chiefly for the purpose of providing sufficient data for obtaining the important conditions of minimum cylinder weight that the preparation of these tables was undertaken. These conditions will be considered, first, when the effects of the thickness of the cylinder wall upon the storage capacity are neglected, and, second, when these effects are taken into account.

MINIMUM WEIGHT OF CYLINDER, NEGLECTING EFFECTS OF THICKNESS

100 Neglecting the effects of the thickness of the cylinder wall upon the storage capacity, which for the actual conditions of storage for transportation will necessarily be small, it is evident that the minimum weight of the cylinder per unit weight of the carbonic acid contained will correspond to the minimum quotient resulting from dividing the pressure of the carbonic acid by its corresponding density. This becomes evident when it is considered, first, that the weight of the cylinder, for the assumed conditions, will be directly as the pressure exerted by the carbonic acid, since the weight of the cylinder is proportional to the thickness, and the thickness in turn is proportional to the pressure; and, second, that the weight of the cylinder per unit weight of carbonic acid contained will be inversely as the density of the contained acid, that is to say, other things being equal, the weight of a cylinder will become less relatively as the density of the contained acid becomes greater. Now combining these two fundamental relations we are led to the conclusion that the weight of a cylinder relative to that of its contained carbonic acid is a minimum when the pressure of the acid divided by its corresponding density is a minimum.

101 It should be noted here that the above relations apply directly to the shell or cylindrical portion of the carbonic acid cylinder; and also to the whole cylinder, including the heads, when these have circular axial sections that are of the same theoretical strength as the shell.

MINIMUM VALUES OF PRESSURES DIVIDED BY CORRESPONDING DENSITIES

102 Fig. 8 was prepared from Table 3 by dividing the different tabular pressures by their corresponding densities; after which the resulting quotients were plotted, as shown, to a vertical scale of pressure divided by density $\frac{P}{G}$, and to a horizontal scale of pressure in pounds per square inch.

103 A glance at this figure shows that, corresponding to each temperature, there is a well defined minimum quotient of pressure divided by density. For example, the minimum quotients for temperatures of 30, 40, 50, and 60 deg. cent. are seen to correspond to pressures of 1090, 1480, 1830, and 2140 lb. per square inch respectively; or to densities of 0.67, 0.65, 0.62, and 0.60 respectively.

104 Neglecting the effects of the thickness of the wall upon the storage capacity of the cylinder, which, as stated above will necessarily be small for actual commercial conditions, it is apparent that this chart, Fig. 8, shows approximately the conditions of minimum weight of cylinder per unit weight of carbonic acid contained.

105 The following is a more exact solution of this problem, in which the effects of the thickness of cylinder wall upon its storage capacity and the working fiber strength of the steel are taken into consideration.

FORMULA FOR WEIGHT OF STEEL IN SHELL PER POUND OF CARBONIC ACID CONTAINED

106 Let Fig. 7 represent a transverse section of a cylinder that contains carbonic acid under known conditions of density and pressure, the working fiber stress of the material also being known. It is desired to derive a formula that will show the relation of the weight of the shell of the cylinder to the weight of the carbonic acid contained. Let

D = outside diameter of the cylinder in inches.
W = weight of shell in pounds per lineal foot.
w = weight of carbonic acid contained in pounds per lineal foot of cylinder.
t = thickness of cylinder wall in inches.
V = volume in cubic inches of carbonic acid contained per lineal foot of cylinder.

G = specific gravity, or density of the carbonic acid, that of pure water at 4 deg. cent. = 1.
f = fiber stress in wall of cylinder, pounds per square inch.
p = internal fluid pressure, pounds per square inch.

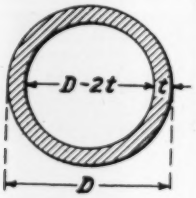

FIG. 7

Then the weight of the shell, or cylindrical portion of the carbonic acid cylinder, in pounds per lineal foot, will equal the continued product of the mean circumference $\pi\ (D-t)$, the thickness t, the length, 12, and the weight of a cubic inch of steel, 0.2833, or

$$W = 10.680\ (D-t)\ t$$

The internal volume of the cylinder in cubic inches per lineal foot, or its capacity for carbonic acid, will be

$$V = \frac{\pi}{4}\ (D-2t)^2 \times 12 = 9.425\ (D-2t)^2$$

The weight of carbonic acid contained, in pounds per lineal foot of cylinder will equal the water capacity of the cylinder per lineal foot multiplied by the density of the carbonic acid, or

$$w = \frac{62.43}{1728}\ VG = 0.03613\ VG = 0.3405\ (D-2t)^2\ G$$

The number of pounds of steel in the cylinder, exclusive of the heads, for each pound of carbonic acid contained will then be

$$\frac{W}{w} = \frac{10.680\ (D-t)\ t}{0.3405\ (D-2t)^2\ G} = 31.37\frac{(D-t)\ t}{(D-2t)^2\ G} \qquad (3)$$

107 In order to arrive at a formula that shall express this relation in terms of the internal fluid pressure and the resulting fiber stress in the cylinder wall we shall first divide both the numerator and denom-

inator of the last member of equation 3 by $(D-t)\,t$. Doing this we get

$$\frac{W}{w} = \frac{31.37}{\left(\frac{D}{t}+\frac{t}{D}-3\right)G} \tag{4}$$

which is a close approximate value of $\frac{W}{w}$, expressed in terms of the density of the carbonic acid and the relation of the thickness to the outside diameter of the cylinder, $\frac{t}{D}$ and $\frac{D}{t}$.

108 An investigation of the relative merits of the different formulae that have been published for the strength of tubes which are subjected to internal fluid pressures, has led the author to the belief that Clavarino's formula is the most reliable, when the tube wall is subjected to both the transverse and longitudinal stresses due to the internal fluid pressure; as is the case in a carbonic acid cylinder. Unfortunately this formula is too complex in form for direct substitution of values for $\frac{t}{D}$ and $\frac{D}{t}$ in equation 4.

109 The author, however, has produced an exceedingly close approximation to Clavarino's formula for values of $\frac{t}{D}$ less than 0.1; which fully covers the range in values of $\frac{t}{D}$ for the conditions of minimum weight of cylinder per unit weight of contained carbonic acid. This very close approximate formula, for steel carbonic acid cylinder conditions, gives the relations

$$\frac{D}{t} = 2.325\,\frac{f}{p}, \text{ or } \frac{t}{D} = 0.43\,\frac{p}{f} \tag{5}$$

Now substituting these values of $\frac{D}{t}$ and $\frac{t}{D}$ in equation 4 we get

$$\frac{W}{w} = \frac{31.37}{(2.325\,\frac{f}{p} + 0.43\,\frac{p}{f} - 3)\,G} \tag{6}$$

which expresses the relation of the weight of steel in one unit length of the shell to the weight of the carbonic acid contained in a unit length; this relation being expressed in terms of the density and pressure of the carbonic acid, and of the working fiber stress of the steel.

MOST ECONOMIC CONDITIONS OF STORAGE AND TRANSPORTATION

110 Formula 6 makes it possible to investigate fully the conditions that correspond to the minimum weight in the shell of a carbonic acid cylinder per unit weight of contained acid. The results of such an investigation are shown in Fig. 9, and in Table 7. Values for the density G, and the corresponding pressure p, for temperatures ranging from 90 to 140 deg. fahr., as taken from Table 4, were substituted in formula 6, together with 15 000 lb. per square inch for the working fiber stress in the cylinder wall. The results obtained are shown plotted in Fig. 9, to a vertical scale of weight of shell divided by weight of the acid contained, each per lineal foot, and to a horizontal scale of fluid pressure exerted by the carbonic acid, in pounds per square inch.

111 It will be observed that each temperature curve of this figure has a well defined minimum ordinate, or ratio of weight of shell to weight of contained acid. For example, when the carbonic acid cylinder and its contents are at a temperature of 110 deg. fahr. this minimum ordinate corresponds to a density, or proportion of filling by weight in water capacity G, of 0.628; and to a fluid pressure within the cylinder p, of 1575 lb. per square inch. These then are the most economic conditions of storage and transportation of carbonic acid, when the maximum temperature of the cylinder while charged is 110 deg. fahr.; for it is apparent from the form of the curve that, for any given degree of safety, either a less or a greater proportion of filling will require a greater weight of steel in the cylinder wall per unit weight of contained carbonic acid than will be required for the most economic conditions.

112 Similarly the most economical conditions of storage for transportation have been obtained for fiber stresses ranging from 15 000 to 30 000 lb. per square inch and for maximum storage temperatures ranging from 100 to 155 deg. fahr. Table 7 shows these results put into the most convenient form for the design, on a rational basis, of carbonic acid cylinders.

THICKNESS FACTORS FOR CARBONIC ACID CYLINDERS

113 Table 7 is based upon the results of laboratory experiments on purified and dried carbon dioxid. It is therefore directly applicable to the storage in steel cylinders of chemically pure carbonic acid.

114 In order to determine the applicability of Table 7 to the design of steel cylinders for the storage and transportation of commercial carbonic acid the author conducted a series of experiments on commercial carbonic acid under the precise conditions of commercial storage for transportation, an account of which will be found recorded in Part 2 of this paper. The results of these experiments show for commercial acid, fully saturated with water vapor, that an air content of one per cent will cause an increase in the thickness factors contained in Table 7 of about 4 per cent.

APPLICATION OF TABLE 7 TO THE DESIGN OF CARBONIC ACID CYLINDERS

115 It will be observed that the main entries of this table are thickness factors, each of which represents, for the condition of minimum weight of steel in the shell, the quotient obtained by dividing the thickness of the shell by its outside diameter, or $\frac{t}{D}$, both being expressed in inches.

116 Before attempting to apply this table to the design of commercial carbonic acid cylinders, it will be found necessary, of course, to determine, first, the greatest safe working fiber stress of the steel constituting the finished cylinder, and, second, the greatest temperature that the contents of the charged cylinder will reach under the ordinary conditions of the commercial storage and transportation of the acid.

117 Any discussion of these matters would be clearly outside the province of the present paper, which is distinctly a monograph on those physical properties of carbonic acid that have a bearing upon rational methods of cylinder design and, as well, upon investigations into the stresses to which charged cylinders are subjected.

118 Assuming, for instance, the maximum working fiber stress in the wall of a cylinder to be 17 000 lb. per square inch, and the maximum storage temperature of the carbonic acid to be 120 deg. fahr., we find from Table 7 the corresponding thickness factor, $\frac{t}{D}$, to be 0.0443. For these conditions, then, a cylinder of $5\frac{1}{2}$ in. outside diameter should have a thickness t, equal $0.0443 \times 5\frac{1}{2}$, or 0.244 in.; which is approximately $\frac{1}{4}$ in.

CHARGING FACTORS FOR CARBONIC ACID CYLINDERS

119 At the bottom of Table 7 will be found a set of charging factors, for determining the quantity of acid to be charged into cylinders, that have been designed by use of the corresponding thickness factors. It will be observed that for any given maximum storage temperature the corresponding charging factor is expressed in three different ways, namely, first, as pounds carbonic acid per pound water capacity, which for the above example, where the maximum storage temperature is assumed to be 120 deg. fahr. would be 0.61; second, as pounds carbonic acid per cubic inch of cylinder capacity, which for the conditions of the above example would be 0.0220; and, third, as pounds carbonic acid per U. S. gallon of cylinder capacity, or for the above example, 5.07.

120 In order then to have a cylinder carry 20 lb. of acid at a maximum storage temperature of 120 deg. fahr., when the cylinder is designed according to Table 7, it should have a water capacity of $20 \div 0.61 = 32.8$ lb.; or it should have a cubic capacity of $20 \div 0.0220 = 910$ cu. in.; or, it should have a capacity of $20 \div 5.07 = 3.95$ U. S. gal.

APPLICATION OF TABLE 7 TO DETERMINING STRESSES IN CARBONIC ACID CYLINDERS

121 In Part 1 of this paper will be found a full explanation of Table 4, the entries of which are the absolute fluid pressures of pure carbonic acid, in pounds per square inch, corresponding to the different temperatures and densities tabulated, the densities being referred to pure water at its maximum density, all weighings being reduced to vacuo.

122 When applying this scientific table to ordinary commercial conditions, for weights of acid that are known to be accurate only to within a pound and to temperatures of the acid that are known to be accurate only to within 5 deg. fahr.; no correction need be applied to the values given in Table 4; unless the air content of the acid is excessive, in which case a correction should be made which, for temperatures ranging from 100 to 140 deg. fahr., will average about 60 lb. increase in tabular pressure for each per cent of air contained in the carbonic acid.

123 For calculating the fiber stress in the wall of a carbonic acid cylinder use formula 5 contained in Part 2 of this paper, which is

$$f = 0.43 \frac{pD}{t} \text{ where}$$

f = fiber stress in cylinder wall in pounds per square inch of material.
p = internal fluid pressure in pounds per square inch.
D = outside diameter in inches.
t = thickness of cylinder wall in inches.

124 It should be remarked here that this simple formula gives results which, for carbonic acid cylinder conditions, approximate exceedingly close to those obtained by use of Clavarino's theoretically correct formula which is

$$f = \frac{4\ D^2 + (D-2t)^2}{3\ [D^2 - (D-2t)^2]} p \qquad (7)$$

125 For a cylinder having a water capacity of 33 pounds when charged with 20 pounds of commercial acid, corresponding to a tabular density of $\frac{20}{33}$, or 0.61, and having an air content of 2 per cent, when at a temperature of 120 deg. fahr., will be subjected to a fluid pressure, according to Table 4, of 1760 + (60 × 2), or 1880 pounds per square inch. If now this cylinder have an outside diameter of $5\frac{1}{2}$ in. and a thickness of wall of $\frac{1}{4}$ in., then the fiber stress in the wall will be

$$f = 0.43 \frac{pD}{t} = 0.43 \frac{1880 \times 5.5}{.25} = 17\,800 \text{ lb. per sq. in.}$$

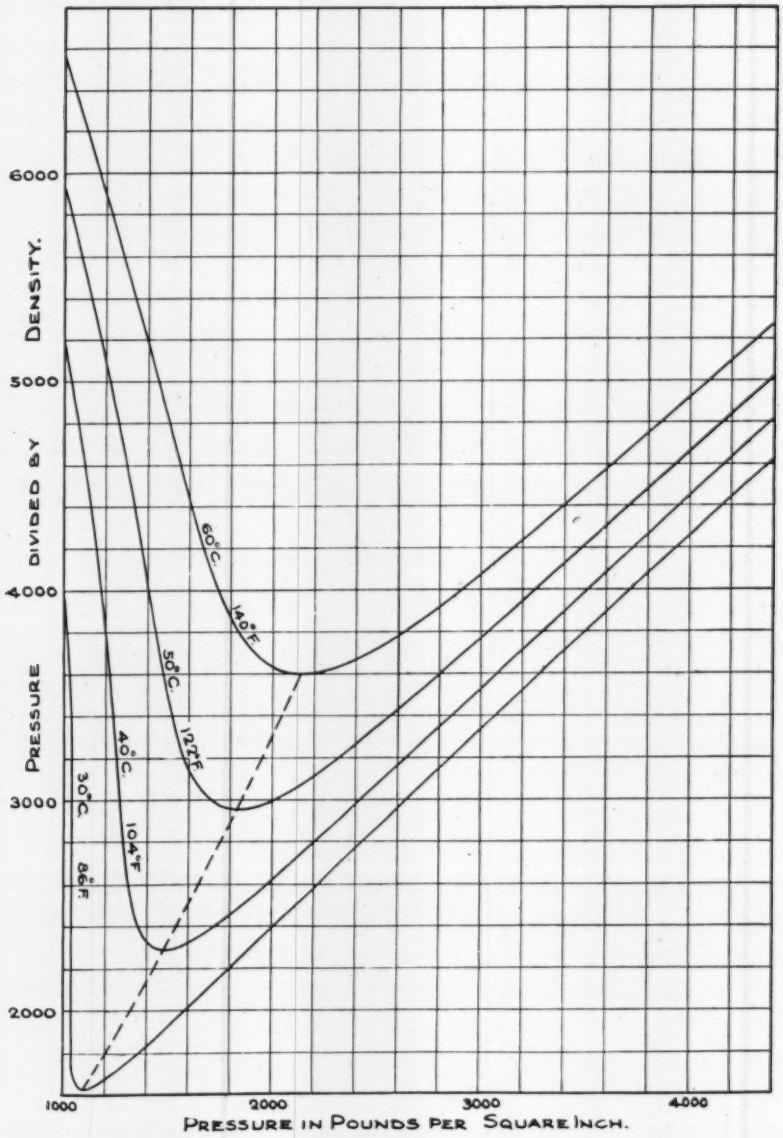

FIG. 8 CURVES SHOWING THE RELATION OF PRESSURE DIVIDED BY DENSITY TO THE PRESSURE OF CARBONIC ACID

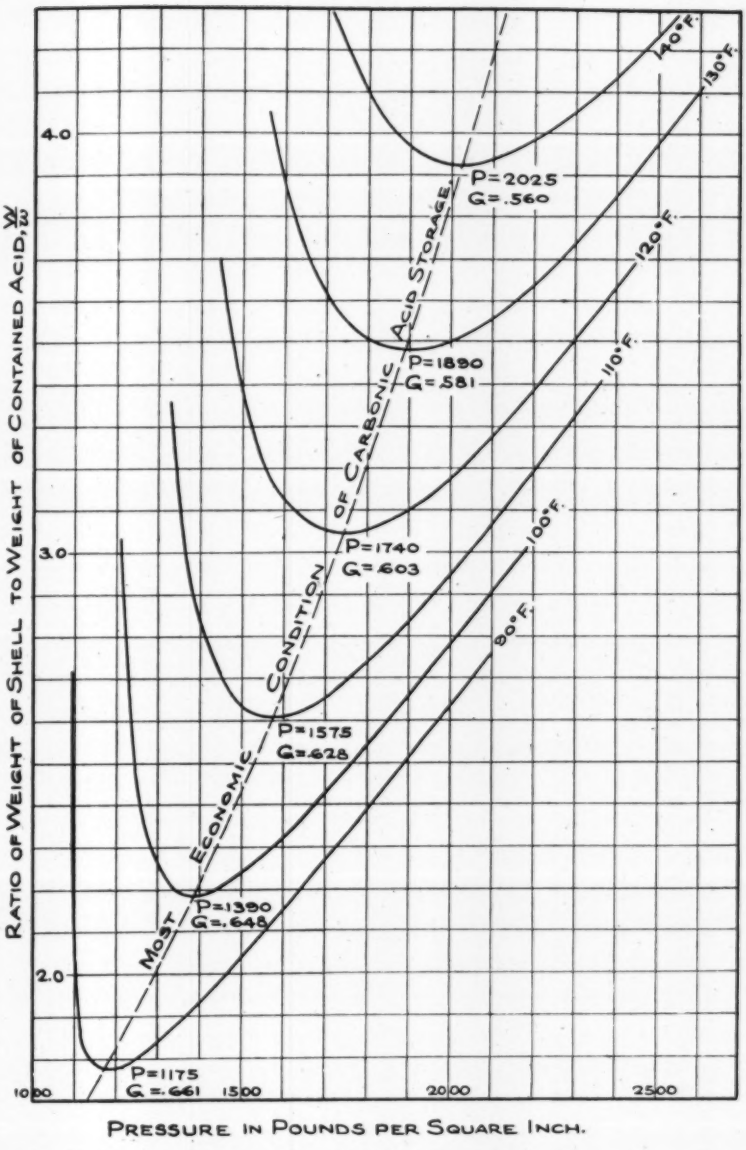

FIG. 9 MOST ECONOMIC CONDITION OF CARBONIC ACID STORAGE FOR FIBER STRESS OF 15 000 LB.

TABLE 7 THICKNESS AND CHARGING FACTORS FOR CARBONIC ACID CYLINDERS CORRESPONDING TO THE CONDITION OF MINIMUM WEIGHT OF STEEL IN THE SHELL PER UNIT WEIGHT OF ACID CONTAINED

RULE:—TO FIND THE THICKNESS OF CYLINDER WALL, MULTIPLY THE OUTSIDE DIAMETER BY THE THICKNESS FACTOR CORRESPONDING TO THE WORKING FIBER STRESS AND GREATEST STORAGE TEMPERATURE

Fiber Stress in Wall, Pounds per Sq. Inch.	GREATEST TEMPERATURE TO WHICH CHARGED CYLINDER IS SUBJECTED.											
	100°F	105°F	110°F	115°F	120°F	125°F	130°F	135°F	140°F	145°F	150°F	155°F
	FACTORS FOR THICKNESS OF CYLINDER WALL, OR t/D.											
15000	.0398	.0426	.0452	.0476	.0499	.0521	.0542	.0562	.0581	.0599	.0616	.0633
16000	.0375	.0401	.0425	.0449	.0470	.0491	.0511	.0530	.0547	.0564	.0581	.0597
17000	.0353	.0378	.0401	.0423	.0443	.0463	.0482	.0500	.0515	.0532	.0548	.0563
18000	.0334	.0357	.0379	.0400	.0419	.0438	.0455	.0472	.0487	.0503	.0518	.0533
19000	.0316	.0338	.0359	.0378	.0397	.0415	.0432	.0448	.0462	.0477	.0492	.0506
20000	.0300	.0321	.0341	.0359	.0377	.0394	.0410	.0425	.0439	.0454	.0468	.0481
21000	.0286	.0306	.0325	.0342	.0359	.0375	.0391	.0406	.0419	.0433	.0446	.0459
22000	.0273	.0292	.0310	.0327	.0344	.0359	.0374	.0388	.0401	.0414	.0427	.0439
23000	.0261	.0279	.0297	.0313	.0329	.0344	.0358	.0372	.0385	.0397	.0409	.0421
24000	.0251	.0268	.0285	.0300	.0316	.0330	.0344	.0357	.0370	.0381	.0393	.0405
25000	.0241	.0258	.0274	.0289	.0303	.0317	.0331	.0344	.0356	.0367	.0379	.0390
26000	.0232	.0248	.0264	.0278	.0292	.0306	.0319	.0331	.0343	.0354	.0365	.0376
27000	.0223	.0239	.0254	.0268	.0282	.0295	.0307	.0320	.0331	.0342	.0353	.0363
28000	.0215	.0231	.0245	.0259	.0272	.0285	.0297	.0309	.0320	.0331	.0341	.0351
29000	.0208	.0223	.0237	.0250	.0263	.0275	.0287	.0299	.0309	.0320	.0330	.0340
30000	.0202	.0216	.0229	.0242	.0254	.0266	.0278	.0289	.0299	.0310	.0320	.0329
These charging factors are substantially correct for fiber stresses from 15,000 to 30,000 lbs. per square inch	MEAN DENSITY, OR POUNDS OF CARBONIC ACID PER POUND WATER CAPACITY.											
	.65	.64	.63	.62	.61	.60	.59	.58	.57	.56	.55	.54
	MEAN WEIGHT OF CARBONIC ACID IN POUNDS PER CUBIC INCH.											
	.0235	.0232	.0228	.0224	.0220	.0216	.0212	.0208	.0205	.0201	.0198	.0196
	MEAN WEIGHT OF CARBONIC ACID IN POUNDS PER U.S. GALLON.											
	5.42	5.36	5.27	5.17	5.07	4.98	4.90	4.82	4.73	4.65	4.57	4.51

ADDENDUM

126 The present paper, it is believed, furnishes data on the physical properties of carbonic acid of sufficient scope for the design of carbonic acid cylinders on a rational basis and for the investigation of the safety of cylinders that are now in use. While complete in itself, this paper is based, so far as cylinder design and investigation for safety are concerned, upon assumed safe working fiber stresses of the material constituting the cylinder wall. The engineer who undertakes to design cylinders for the transportation of carbonic acid, in addition to what is here given, should also be in possession of sufficient knowledge of the properties of the different steels in their relation to processes of cylinder manufacture, heat treatment, and usage to which the commercial cylinders are subjected, to be able to select the material best suited to cylinder construction.

127 There appears to be the greatest diversity of opinion regarding the most suitable material for cylinder construction. For example, in Great Britain, those engaged in compressing carbonic acid for transportation are following substantially the recommendations of the report to Parliament in 1896 of the Committee on the Manufacture of Compressed Gas Cylinders. This Committee recommended the following as a suitable steel for the purpose, namely:

> Carbon not to exceed 0.25 per cent.
> Iron not to be less than 99 per cent.
> Elongation on an 8-in. test piece cut from the finished cylinder not to be less than 15 per cent.
> Tensile strength ditto not to be less than 28 tons (63 000 lb.), or more than 33 tons (74 000 lb.).

128 These mild steel cylinders are annealed before being put into service and are reannealed, while in service, once every three or four years.

129 This material is in striking contrast to that used in the light weight German cylinders and in the seamless cylinders that have been generally manufactured in the United States, which material has a high elastic limit and a correspondingly low ductility. In the United States it is not customary to submit the cylinder while in service to periodic annealings. Indeed it has not even been heretofore customary for the manufacturer to anneal the finished cylinders. Average

values of the physical properties of the steel constituting these light weight cylinders would be:

Carbon, 0.55 per cent.
Elongation in 8 inches, 12 per cent.
Yield point, 55 000 lb.
Tensile strength, 95 000 lb.

130 In the United States by far the greatest number of carbonic acid cylinders thus far manufactured have been made from lap-welded bessemer steel tubes, having the following average physical properties:

Elongation in 8 inches, 22 per cent.
Yield point, 37 000 lb.
Tensile strength, 58 000 lb.

131 The British companies engaged in compressing carbonic acid for transportation point with pride to the fact that not one of their mild steel cylinders has yet exploded when in service, while no such claim can be made for the cylinders commonly manufactured either in Germany or in the United States.

132 In the United States there are no rules and regulations whatever relating to the storage and transportation of carbonic acid, either by the government or by the transportation companies. In this respect we stand in striking contrast to such nations as Great Britain, Germany, France, etc., where the transportation of carbonic acid is conducted under regulations more or less effective.

133 The only safeguarding of employees and of the public at large in the United States has been the universal practice of subjecting all newly made cylinders to a single hydrostatic test. The hydrostatic pressure commonly used is entirely sufficient, so far as mere pressure is concerned; and if this one hydrostatic test was in itself sufficient to safeguard the public at large, then every resident of the United States should feel perfectly safe when in proximity to a charged carbonic acid cylinder. But when it is considered that the success of a hydrostatic test is due to the tenacity of the material alone and not to its ductility or toughness, and could therefore be just as successfully applied to cylinders made of brittle as to those made of ductile and tough material, it becomes apparent that this test alone is not sufficient. The writer has frequently handled experimentally a glass tube containing carbonic acid under

the conditions of commercial storage for transportation, which could have withstood successfully the customary hydrostatic test to which commercial steel cylinders are subjected.

134 The customary hydrostatic test applied to compressed and liquefied gas cylinders can serve but one legitimate purpose, namely, to indicate the presence of concealed defects, such as thin places in the wall, bad welds, cracks, etc. Any attempt to apply this test to new cylinders for any other purpose will be apt to do more harm than good. Of course this statement applies only to cylinders that are to be put into service and not to those that have been selected for testing to destruction. A proper safeguarding of the public would require that this customary hydrostatic test should be coupled with a satisfactory commercial test designed to determine whether or not the material of the finished cylinder will be capable of successfully resisting the usage, or rather the ill usage, to which carbonic acid cylinders are subjected when in service. It should be recognized in this connection that any scheme of commercial tests, when applied to well designed cylinders constructed of suitable material, should aim only at indicating and eliminating the occasional cylinder or group of cylinders, which if put into service may become a menace to the public, either because of defective material or defective construction. This should be accomplished without damaging the good cylinders in any way. Any scheme that necessarily overstresses the good cylinders in order to eliminate the occasional defective ones is highly improper, notwithstanding the fact that such tests have been in common use.

135 In the body of this paper the economics of cylinder design has been fully treated from the standpoint of the physical properties of the carbonic acid. The economics of cylinder construction and maintenance yet remains to be treated. In this Addendum the situation has been sufficiently reviewed to indicate the necessity of a further investigation of the cylinder problem. It is apparent that the magnitude and importance of the compressed and liquefied gas industries, involving as they do the constant circulation of hundreds of thousands of charged cylinders, each a magazine of stored energy, are sufficient to warrant a thorough investigation, first, of the suitability of materials for cylinder construction, second, satisfactory tests for new cylinders, and third, periodic inspection, treatment, and tests of cylinders while in service. Such an investigation should be of sufficient scope to furnish data for the formulation of a set of standard specifications for compressed and liquefied gas cylinders;

which shall on the one hand guarantee for every cylinder put into service sufficient thickness of wall and toughness of material for the proper safeguard of the public, and on the other hand that neither of these shall be so excessive as to involve the unnecessary expenses due to unnecessary weight.

THE TOTAL HEAT OF SATURATED STEAM

By Dr. Harvey N. Davis, Cambridge, Mass.
Non-Member

For many years Regnault's classic formula, now 61 years old, which gives as the total heat of saturated steam

$$H = 1091.7 + 0.305\ (t - 32)\ \text{B.t.u.}$$

has been exclusively used by engineers in this country. This is a well deserved tribute to his extraordinary genius and painstaking skill—no one can possibly read his original memoirs without a new and constantly increasing respect and admiration for him; nevertheless, the remark is becoming common in the literature of engineering research that such and such a method cannot be used because of the well known errors in the steam table. It is therefore fortunate that, at least in the range from 32 to 212 deg., physicists have recently provided a considerable number of good observations of the total heat of saturated steam apparently not noticed by the makers of our steam tables. It is equally unfortunate that, in all these years, there seems to have been not a single new observation above the boiling point. It is the purpose of this paper to show that certain observations recently made for very different purposes can be combined to give a better set of values of H above 212 deg. than do Regnault's direct measurements, and to propose a new formula for the range from 212 to 400 deg., the accuracy of which is believed to be something like 0.1 per cent. If these results are correct, Regnault's formula is too high by more than 18 B.t.u., or 1.7 per cent at 32 deg.; too low by 6 B.t.u., or 0.5 per cent at 275 deg.; and too high again above 380 deg., the error increasing rapidly at high temperatures.

To be presented at the New York Meeting (December 1908) of the American Society of Mechanical Engineers.

The professional papers contained in The Journal are published prior to the meetings at which they are to be presented, in order to afford members an opportunity to prepare any discussion which they may wish to present. They are issued to the members in confidence, and with the understanding that they are not to be published even in abstract, until after they have been presented at a meeting. All papers are subject to revision.

The Society as a body is not responsible for the statements of facts or opinions advanced in papers or discussions. C55.

2 Some years ago, attempts were made to determine the variation of the specific heat of superheated steam with pressure and temperature by means of throttling or wire-drawing experiments. These attempts failed because, as the observers themselves pointed out, the necessary computations were extremely sensitive to small errors in the assumed values of the total heat of saturated steam. Under unfavorable circumstances, an error of 0.1 per cent in one of the values in the steam tables might make a difference of from 3 to 5 per cent in C_p. It is then evident that, knowing C_p independently, one could reverse the process by which they tried to get it, and compute all the total heats in terms of any one by a method as insensitive to errors in assumed data as the other was sensitive. This process will be described later.

3 Fortunately, since these experiments, C_p has been determined independently and directly by Knoblauch and Jakob of Munich and by Thomas of Cornell, and it will presently be shown that the accuracy attained by them is sufficient to make worth while such a recomputation of the wire-drawing experiments.

4 In this work Knoblauch's values of C_p will be used rather than Thomas'. Some reasons for this have been presented to the Society in connection with Heck's recent paper on The Thermal Properties of Superheated Steam, and need not be repeated. Any not persuaded of the wisdom of that opinion may still have considerable confidence in this work, not only because of the general insensitiveness of the method to errors in C_p, but particularly because practically all the values of C_p involved are at low pressures and very moderate superheats, and in this corner of the diagram there is less question as to the accuracy of Knoblauch's values than elsewhere; furthermore because, even had Heck's values been used as printed, the resulting total heat of saturated steam would have been increased by less than 3 B.t.u. at 400 deg., the increase becoming continually smaller as one approached 212 deg. This is not an estimate of the limit of error of the new formula; it is rather the worst opinion of it which an unfavorable critic could have.

5 The throttling experiments used are those of Grindley, in England, in 1900, of Griessmann, in Germany, in 1904, and of Peake, in England, in 1905. The agreement which will be shown to exist between the results obtained from these three different sources will be another reassuring proof of the insensitiveness of the method to errors of observation in its assumed data, for the three sets of throttling curves show the obvious differences to be expected in independ-

ent researches. The agreement of results is the more noteworthy when it is remembered that the precautions against radiation and other losses were very different in the three cases. Grindley used a thick glass throttling plate and an independent and independently heated steam "cosie" or jacket, and calibrated his thermometers indirectly by means of Regnault's pressure temperature curve;[1] Peake used a thin mica throttling plate, put wire gauze in the path of the steam to insure thorough mixing, jacketed the low pressure chamber with the escaping steam itself, and used thermometers calibrated by comparison with a previously standardized platinum resistance thermometer; while Griessmann replaced both throttling plate and jacket by a porous plug in a box-wood mount, heavily lagged, in imitation of Joule and Thomson's famous plug experiment, and used thermometers calibrated both by comparison with Reichsanstelt standards and indirectly by means of a steam table.

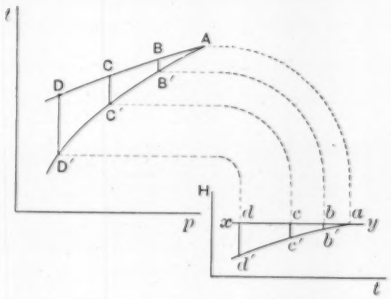

FIG. 1 FIG. 2

SHOWING HOW THE TOTAL HEAT CURVE $yb'c'd'$ IS OBTAINED FROM A THROTTLING CURVE $ABCD$

6 The method of recomputing these throttling experiments is illustrated by Fig. 1 and 2. Fig. 1 represents a throttling curve of the sort published in the three papers to be discussed. Supposedly dry and saturated steam at the pressure and temperature corresponding to the point A is first throttled to a lower pressure and temperature corresponding to the point B; then in a later experiment in the same run, it is throttled from exactly the same initial condition A to the condition C; then to D and so on. The well known law of throttling is that the total heat in the condition B, or C, or D, is equal to that in the initial condition A.

[1] As an extra precaution, all of his temperatures have been recomputed for this paper with the best modern data.

7 The point B represents superheated steam at the pressure p_B; the point B' represents saturated steam at the same pressure; and the amount of superheat at B is the known temperature there minus the temperature at B', which can be taken from a steam table. Also, by definition, the total heat at B equals that of saturated steam at the same pressure (point B') plus the amount of heat required to superheat it at constant pressure from B' to B. This is the integral of C_p from B' to B, or simply the mean C_p from saturation multiplied by the known superheat. If C_p is known, this integral, or increment in the total heat between B' and B, is easily evaluated.

8 This integral is not only the difference between the total heat of saturated steam at B' and that of superheated steam at B; it is also the difference between the total heat of saturated steam at B' and that of saturated steam at A; that is, between the two corresponding ordinates of the curve that gives the total heat of saturated steam as a function of the temperature, the curve sought in this paper. To draw a piece of this curve, one chooses arbitrarily some horizontal line such as xy in Fig. 2, and lays off below it, at the proper temperatures, the distances bb', cc', dd', etc., which represent on the desired H-scale the integrals or total heat differences between B' and B, C' and C, D' and D, etc. The curve $ab'c'd'$ is an isolated piece of the true curve of total heat against temperature. The *relative* height of its points, that is, its shape, is accurately determined; the *absolute* height above the usual zero of total heats, namely, that of water at 32 deg. fahr., is as yet wholly unknown. The experiments of Grindley gave seven independent sample pieces of this sort, one for each throttling curve, their temperature ranges being known and greatly overlapping; similarly Griessmann's data gave eleven such sample pieces, and Peake's six.

9 One chief difficulty in the original work was that the steam at A was often not quite dry so that its condition was not determined by the observed pressure and temperature. All the initial points, such as a, have therefore been omitted from the sample curves. This does not affect the validity of the reasoning about the remaining points, as $b'c'd'$, etc.

10 All sample pieces of any one observer were then plotted carefully on very thin transparent rice paper, with vertical guide-lines at certain standard temperatures, which enabled these plots to be accurately oriented as far as rotation and horizontal displacement were concerned, but left them free to slide up and down over each other. The sheets were then piled on top of one another on a trans-

parent table lighted from below, each one placed so as to make its piece of curve coincide most satisfactorily with the overlapping pieces already laid down. The exact relative displacements of the sheets were then carefully measured. This process was repeated for each of the three observers' sets of sheets independently, four different times for each set, in two very different orders and in those orders reversed, on different days, all with the object of avoiding as far as possible any routinizing effects of memory or habit which might disturb the real independence of the four determinations. The means of the measured displacements were then used to reduce each of the pieces of curve in any one of the sets arithmetically, not graphically, to a zero common to all the curves of that set. The results are marked *Gy*, *Gs*, and *P* in Fig. 3. They are plotted separately for clearness, but they are simply different experimental determinations of exactly the same real curve. The vertical scale of each is four calories[1] to the square. The height of each above its true zero is still unknown. Each of the circles represents at least one independent throttling observation, and some few of them two or three independent observations that happened to coincide. It will be noticed that no one of the curves is more than a tenth of a square wide between centers. Each therefore seems a good determination of the true curve within two-tenths of a calorie, which is less than 0.4 B.t.u.

11 The next step was to establish a comparison between the three curves. The points of each were first grouped in segments of some 20 deg. and the mean point of the group was used to represent the group. There were eighteen such means, seven representing Grindley's points, five Griessmann's and six Peake's. These means were then plotted to scale on three sheets of rice paper and fitted together in the way already described. The result is shown in the next lower curve in Fig. 3. The absolute height of the curve as a whole is still arbitrary. The reader can now judge for himself as to the agreement of the results obtained from the three independent sources.

12 The formula chosen to represent this curve is of the second degree in the temperature. This form is justified and was indeed suggested, by plotting on a single diagram the derivatives of the three curves *Gy*, *Gs* and *P* considered separately. These derivatives agree remarkably with each other in determining a straight line, much

[1] For convenience all diagrams are left in the metric units in which they were computed.

better than could have been expected of the derivative of an empirical function. A more complicated representation is wholly unnecessary, and unwarranted by their limit of error.

13 Assuming the general formula

$$H = H_{212} + a\,(t - 212) - b\,(t - 212)^2$$

the constants a and b were determined by the method of least squares, using all eighteen mean points reduced to a common but arbitrary zero. The results were checked by the usual least squares methods, practically insuring accuracy; but as a rough preliminary check the constants were determined from three random points, one at each end of Grindley's curve and one in the middle, and these coefficients agreed with those afterward obtained within a third of one per cent of their own values, which means less than one hundredth of one per cent in H itself throughout the range of the formula. The agreement of the three curves with their mean is obvious.

14 The resulting formula, in English units, is

$$H = H_{212} + 0.3745\,(t - 212) - 0.000550\,(t - 212)^2$$

This formula gives the total heat of saturated steam between 212 deg. and about 400 deg. *in terms of that at 212 deg.* A value for this fundamental constant H_{212} will presently be chosen from those available in the literature of the subject, but it should be remembered that even if this choice is wrong or if new and different data near 212 deg. are hereafter published, whatever merit the above equation may have will be wholly unaffected by the necessary change in H_{212}.

15 It is interesting to compare the self-consistency of this work, as represented by the narrowness of the bands of plotted points, with that of Regnault's observations, which are plotted at the bottom of Fig. 3.[1] His band is at least eight or ten times as wide as any of those above it. It should also be noticed that something evidently happened to his apparatus at 178 deg. cent. and that allowing for this, his band shows unmistakably the same curvature as those above it. The observations above 178 deg. cent. were, as a matter of fact, the last he made, and he speaks definitely of serious trouble with his apparatus at the very point at which the jump occurs; in fact he had to renew many of its parts, and to watch it continually thereafter, so that his conditions may well have been somewhat

[1] The large circle at the boiling point, 100 deg. cent., represents the mean of 38 points, of which only the highest and lowest are plotted.

changed. This discontinuity in his curve has been noticed by many writers, one of whom attributes it to a leak in his distributing valve, remedied at this point, but this is not definitely mentioned in the memoir.

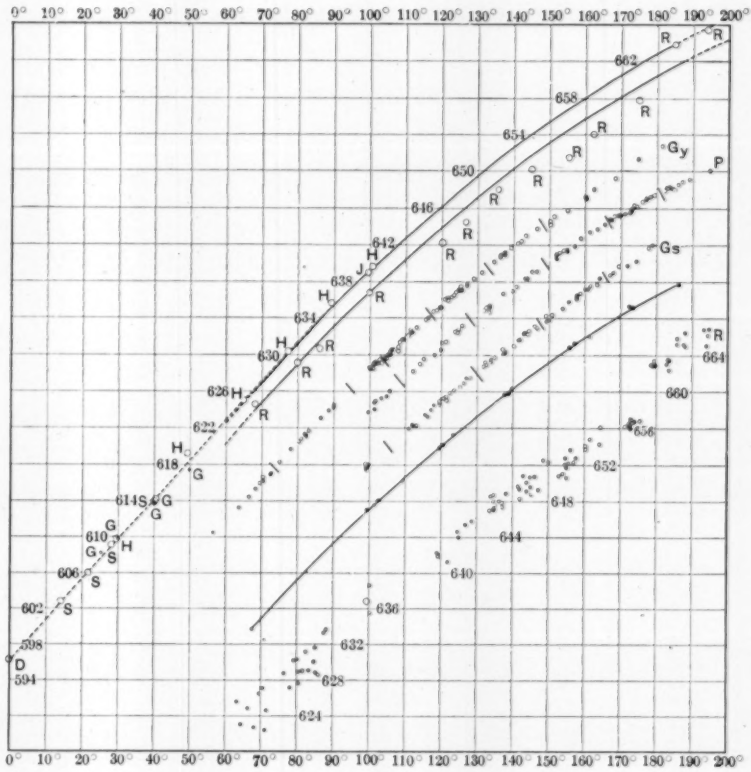

FIG. 3 CURVES OF THE VARIATION OF TOTAL HEAT WITH TEMPERATURE (IN CALORIES AGAINST DEG. CENT.)

GY P AND GS ARE CURVES FROM THE DATA OF GRINDLEY, PEAKE AND GRIESSMAN. THE LINE BELOW THEM SHOWS THEM SUPERPOSED. AT THE BOTTOM (CURVE R) ARE REGNAULT'S OBSERVATIONS PLOTTED ON THE SAME SCALE FOR COMPARISON. AT THE TOP ARE THE VALUES OF DIETRICI (D), A. W. SMITH (S), GRIFFITHS (G), HENNING (H), JOLY (J), AND REGNAULT (R), WITH THE CURVE BELOW REPRESENTED AS ATTACHED BOTH TO REGNAULT'S VALUE AT 100 DEG. CENT. AND TO THE MEAN OF HENNING'S AND JOLY'S VALUES THE LATTER IS SEEN TO BE PREFERABLE

16 All results that could help in the evaluation of the fundamental constant H_{212} have recently been admirably summarized by Professor Smith of the University of Michigan, whose paper has been most useful throughout this work. These results are collected in

Table 1 and are plotted as the top curve in Fig. 3, with the movable section that has been built up in this paper represented as attached, first to Regnault's mean at the boiling point, and second to the mean of the values of Henning and Joly. It will be noticed, first, that in either case most of Regnault's values are too low;[1] this was to be expected, as we have begun only recently to realize the difficulty in removing the last traces of unevaporated water from apparently dry

TABLE 1

Observer	Temperature Degrees fahr.	Total heat B.t.u.
C. Dieterici, Königliche Technische Hochschule, Hanover, Germany	32.0	1073.4
A. W. Smith, University of Michigan, U. S. A	57.1	1084.7
	70.1	1090.7
	82.5	1096.2
	103.6	1104.6
E. H. Griffiths, Cambridge, England	86.0	1097.8
	104.3	1104.9
	76.9	1094.5*
	103.9	1104.2*
	121.7	1111.2*
F. Henning, Reichsanstalt, Berlin, Germany	86.2	1097.6*
	120.5	1114.4
	148.7	1124.7
	171.2	1134.5
	192.7	1144.0
	213.1	1151.1
J. Joly, Trinity College, Dublin, Ireland	211.9	1150.0

*These four values were considered by the experimenters less reliable than their other results

steam, and any such moisture would make the results too low; it is therefore probable that his results at the boiling point are also too low for the same reason; second, that if Regnault's mean at 100 deg. cent. is right, his values at the highest temperatures are too high, a deviation hard to explain on any ground;[2] this makes it still more probable that the true value at 100 deg. is at least as high as the mean of the values of Henning and Joly; and third, that although the

[1] They are represented, in groups, by means.

[2] It is hard enough to see why they should suddenly begin to run as high as on the curve; this raises the only doubts that have yet appeared as to the wisdom of the choice of the C_p values used.

less accurately determined lower end of the movable section does not fit particularly well among the fixed points in either case, the agreement is much more satisfactory when the section is oriented on the mean of Henning and Joly. Finally, both of these observers are among the most skillful experimenters of their time, as Regnault was in his; both have had the advantage of improvements in the technique of accurate measurements accomplished in the several decades since Regnault; and both have used methods differing from each other's and from his, and superior to his in sensitiveness and accuracy. For all of these reasons, the mean of their values, namely 1150.3 B.t.u., seems the most probable value of the total heat of saturated steam at 212 deg. fahr.

17 The final formula, in English units, is

$$H = 1150.3 + 0.3745\ (t - 212) - 0.000550\ (t - 212)^2$$

Its range is from 212 to about 400 deg. fahr.; it does not pretend to accuracy below 212 deg.; in that range an accurately drawn graph

TABLE 2

Temperature Degrees Fahr.	Pressure Pounds	Total Heat		Specific Volume	
		New	Peabody	New	Peabody
32.	0.089	1073.4	1091.7	3294.	3395.
100	0.949	1103.6	1112.4	349.7	354.7
212	14.70	1150.3	1146.6	26.76	26.66
281.0	50.	1173.6	1167.6	8.496	8.429
327.8	100.	1186.3	1181.9	4.412	4.409
358.5	150.	1193.4	1191.9	2.998	3.016
381.9	200.	1198.1	1198.4	2.277	2.299
401.0	250.	1201.5	1204.2	1.837	1.858
417.4	300.	1204.1	1209.3	1.540	1.558
426.3	330.	1205.3	1211.9	1.403	1.417

should be used. The dotted line in Fig. 3 indicates the position of what seems the most probable graph; in drawing it Regnault's observations had to be ignored altogether; the agreement among the other more recent authorities is then most satisfactory.

18 The new formula, supplemented by such a graph, is compared with the standard values given, for instance, by Peabody or Reeve, in Table 2 and Fig. 4 and 5. The table gives the new and the old values of the total heat at various temperatures from 32 to 425 deg.,

and also the new and the old values of the specific volume of saturated steam as computed by the usual Clapyron equation

$$V - v = J\,(r/T)\,\frac{1}{d\,p/d\,t}$$

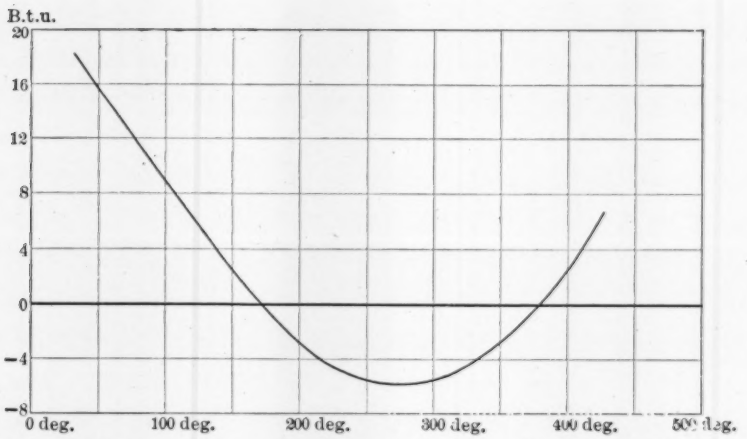

FIG. 4 DEVIATION FROM THE AUTHOR'S VALUES OF REGNAULT'S VALUES OF TOTAL HEAT OF SATURATED STEAM, GIVEN IN PEABODY'S TABLES. HIGH TEMPERATURE END OF CURVE IS A PARABOLA

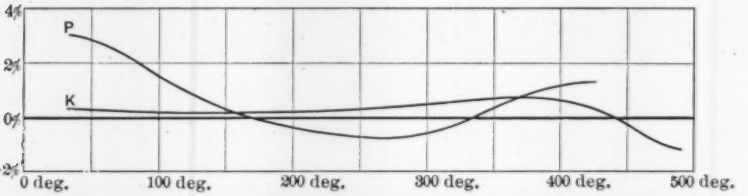

FIG. 5 PERCENTAGE DEVIATION OF REGNAULT'S VALUES OF SPECIFIC VOLUME OF SATURATED STEAM, GIVEN IN PEABODY'S TABLES, AND OF KNOBLAUCH'S EXPERIMENTAL VALUES, FROM THE NEW VALUES—EVERYTHING ABOVE 400 DEG. EXTRAPOLATED

The necessary values of dp/dt were taken from Henning's recent and valuable review of the available literature.[1] In Fig. 4, the deviation of the standard values of H from those here presented is shown graphically. In Fig. 5 the percentage deviation of the standard values of V from the new ones is similarly presented. This diagram also shows, in the curve marked K, the deviation of Knoblauch's experimental

[1] Wied. Ann. 22 (1907), p. 609.

values, as given by Linde's equation,[1] from those of this paper. The agreement is gratifyingly good up to 400 deg.; above that both equations are extrapolated, so that some disagreement is not surprising.

19 These total heat values can be made to throw new light on a subject recently discussed before this Society by Professor Heck, namely, the specific heat of superheated steam. It has several times been pointed out in the literature that, *along the saturation line,*

$$C_p = \frac{dH}{dt} - \frac{r}{T} + \frac{r}{u}\left(\frac{dv}{dt}\right)_p$$

where H is the total heat of saturated steam, r its heat of vaporization, u the change of volume during vaporization, t the ordinary and T the absolute temperature, and $\left(\frac{dv}{dt}\right)_p$ a derivative out into the superheated region like C_p itself. Not much use has hitherto been

TABLE 3

Pressure Pounds	Temperature Degrees	*Cp* (Calculated)	*Cp* Knoblauch	*Cp* (Heck)
15	213	0.484	0.470	0.581
35	259	0.506	0.492	0.614
75	308	0.560	0.537	0.650
115	338	0.615	0.584	0.680
195	380	0.722	0.699	0.719
250	401	0.794	0.795	0.739
310	420	0.875	0.919	0.758
370	437	0.956	1.068	0.776
450	457	1.067	1.318	0.798
530	473	1.179	1.634	0.819
610	488	1.293	2.041	0.842

made of this equation because of the outstanding errors in Regnault's values for saturated steam, but it is hoped that the new values of H, r, and u of this paper are good enough to make the computation worth while. The volume derivative is a source of some uncertainty, but fortunately its value needs to be known only on the saturation line itself, and there Linde's characteristic equation for superheated steam is at its best, and seems satisfactory. Certain values of C, computed in this way, are given in Table 3 and are plotted with circles in Fig. 7.

20 This figure also shows the saturation curves of Knoblauch, of Thomas and of Heck. Knoblauch's curve is extrapolated analyt-

[1] See the Forscharb, Berlin, Heft 21, p. 67; or Peabody's Steam Tables, 1907 ed., p. 21.

ically from four points at low pressures, which are themselves extrapolated from observed points at various favorably situated superheats. The extrapolations to saturation may be uncertain by small amounts which are represented in Fig. 5 by short vertical lines attached to Knoblauch's curve. The extrapolation to very high pressures is of course uncertain.

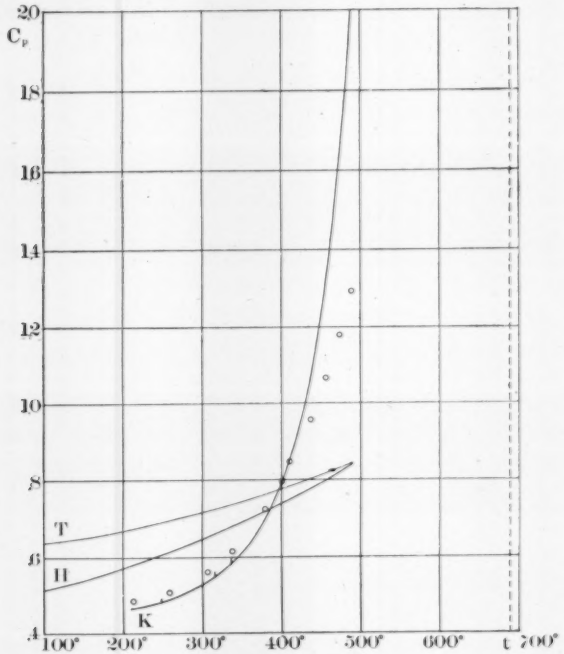

FIG. 6 REPRESENTING THE SATURATION LINE ON THE REGULAR C_p DIAGRAM, AS DRAWN BY KNOBLAUCH (*K*), BY THOMAS (*T*), AND BY HECK (*H*). THE CIRCLES REPRESENT VALUES COMPUTED THERMODYNAMICALLY. THE DOTTED LINE AT THE RIGHT, AT $t = 689$ DEG. = THE CRITICAL TEMPERATURE, SHOULD BE APPROACHED AS AN ASYMPTOTE BY THE TRUE CURVE

21 Thomas' curve has even less experimental foundation if the criticisms already presented in connection with Heck's paper are justified, and would seem to be a sheer guess. Heck's line was presented as a compromise between Knoblauch's and Thomas'. If Thomas' line is discredited, Heck's ceases to be interesting.

22 In view of all this uncertainty the evidence furnished by the thermo-dynamic computation described above would seem to be

of considerable importance. As Fig. 5 shows, the computed points agree with Knoblauch's curve rather than with those of Thomas or Heck, up to about 400 deg. (250 lb.). Above that temperature both Linde's equation and the total heat equation of this paper are extrapolated, and so the computation means very little, but even at high temperatures the general character of the computed curve is more like Knoblauch's than like Thomas' or Heck's.

23 This computation furnishes therefore an additional justification of the use of Knoblauch's values in this paper. It will perhaps be argued that this justification is simply a circular fallacy—in that a set of total heat values based on Knoblauch's values of C_p might be expected to lead back to Knoblauch's values at the end—but a careful consideration of the formulae involved will show that the objection is only in a very small measure well founded, and that the circularity of the reasoning is apparent, not real.

SUMMARY

24 The throttling experiments of Grindley, Griessmann and Peake considered in connection with Knoblauch's determination of the specific heat of superheated steam, lead to a new formula for the total heat of saturated steam, namely

$$H = H_{212} + 0.3745\,(t - 212) - 0.000550\,(t - 212)^2$$

25 The best available value of H_{212} seems to be 1150.3 mean B.t.u., which is the average of the values of Henning and of Joly. The total heat equation becomes

$$H = 1150.3 + 0.3745\,(t - 212) - 0.000550\,(t - 212)^2$$

The range of this formula is from 212 to about 400 deg. fahr. The greatest error in Regnault's formula in this range is 6 B.t.u., at 275 deg. fahr., but if Regnault's formula is extrapolated to higher temperatures, the error in it increases very rapidly. Below 212 deg. there is an abundance of modern data to show that Regnault's formula runs high, the error reaching 18 B.t.u. at 32 deg.

26 Recomputed values of the specific volume of saturated steam differ from the standard values by 101 cu. ft. or 3 per cent at 32 deg. and by about 1 per cent in the opposite direction at 275 deg. Com-

puted values of C_p at saturation agree strikingly with Knoblauch's values, and give additional confirmation to a conclusion already presented to this Society that of the three available sets of C_p values, Knoblauch's, Thomas' and Heck's, Knoblauch's is most deserving of confidence.

27 A steam table based on these new values will presently be published under the joint authorship of Professor Lionel S. Marks and the present writer.

DISCUSSION

THERMAL PROPERTIES OF SUPERHEATED STEAM

By Prof. R. C. H. Heck, Published in May Proceedings

Dr. Harvey N. Davis Professor Heck is undoubtedly right in selecting, from a confused literature, the papers of Knoblauch and Jakob and of Thomas as most worthy of consideration, and fortunately there is substantial agreement between them in the region of moderate superheat, even though their curves look so different that one is liable to be deceived on this point.

2 Nevertheless, as Professor Heck has pointed out, there are three respects in which Knoblauch and Thomas are in serious disagreement. First, Thomas' values at low pressures run very much higher close to saturation than do Knoblauch's. Second, Thomas' values at high pressures run lower close to saturation than Knoblauch's. And third, Thomas' curves do not pass a minimum in the region of high superheat and rise again as Knoblauch and others believe they should. Professor Heck's discussion of the last of these points of disagreement is particularly satisfactory, including his conclusion that Knoblauch's curves rise rather too rapidly. The second will be referred to later in a paper on the total heat of saturated steam to be presented to this Society at its December meeting. It will there be shown that what little evidence there is seems to be with Knoblauch against Thomas. The discussion in this note will be confined to the first of the three matters, the contention being that here also Professor Heck should have decided with Knoblauch against Thomas.

3 The point at issue is whether or not the fundamental curve at 15 lb., and those near it, should swoop suddenly to a considerable height close to the saturation line as do Thomas'. Professor Heck believes that they should, and forces through Knoblauch's experimental points curves which are as nearly like Thomas' in shape as possible.

4 Similarly sudden changes in various properties of superheated steam close to the saturation line have been reported several times before. For instance, Grindley found something exactly similar

in his wire-drawing experiments, and so did Battelli and also Ramsay and Young in their volume measurements; and in every case of this sort, the trouble has invariably been traced to unevaporated water floating in very minute drops in apparently superheated steam. The form which the explanation takes in this particular case is simple. Thomas starts with admittedly wet steam, and, in a preliminary experiment, undertakes to just dry it without any superheating. He believes that he can tell exactly when this has been accomplished by watching for the first jump in his thermo-couple temperature, and justifies this belief by certain control measurements, not described, of the quality of his steam, which measurements would presumably be carried out in a second calorimeter at some distance from the thermo-couple. Every bit of experience hitherto reported by careful observers would lead one to expect that that part of his mixture which is already evaporated would begin to superheat, and the thermo-couple to jump, before the last traces of entrained water had disappeared; and further that evaporation would proceed at the expense of the heat in the steam while the mixture was passing to the place where it was to be examined, so that this examination might wholly fail to detect the wetness of the steam as it was passing the thermo-couple.

5 Knoblauch and Jakob made a careful study of this very point in their electrical preheater, and found experimental proof that water could be held in suspension in very highly superheated steam, and that for the process of evaporation time and thorough mixing were essential, as well as heat. Their apparatus provided for this purpose a complicated grid of wires completely filling a pipe nearly 8 in. in diameter and about 8½ ft. long, with elaborate arrangements for keeping track of the distribution of temperature through both the length and the breadth of the pipe. They state that traces of entrained water were observable through several sections of this pipe, and even if "several" means as few as two, and even if it be assumed that the steam in these sections had always a specific volume as great as that of the still more highly superheated steam in the calorimeter, it is easy to compute that the wetness in their steam persisted for a time which was never less than a second and averaged more than two seconds, and this, too, after *all* of the heat necessary for the high superheat had been put in.

6 In Thomas' apparatus, on the other hand, all the evaporation there was had to take place in 24 quarter-inch holes in a soapstone block, something like 5 in. long, and in a small chamber just above it, and a similar computation shows that even if the specific volume of

the steam was never greater than when saturated, it must have passed the thermo-couple, always within nine-tenths of a second, sometimes within a thirtieth of a second, and on the average within less than half a second of the time when the *first* of the superheating heat was put in. It would, therefore, have been extraordinary if Thomas had not found exactly the apparent swoop which he did, and I believe that this swoop is wholly due to moisture in suspension. Professor Reeve has come to the same conclusion by different reasoning in a recent number of Power.

7 If this contention that Thomas had wet steam in his saturation tests is justified, his data should evidently be recomputed, leaving the saturation tests out of account altogether, as was suggested by Reeve in Power. This makes unavailable several other tests, such as those from No. 80 on, there being nothing with which to compare them. The remaining 59 tests have been grouped in pairs in the usual way; thus, when there were four points, the first was taken with the third and the second with the fourth, and so in general. The results of such a recomputation are given in the following table.

8 This table shows two things. In the first place, none of the 31 values are near enough to the saturation line or far enough apart to give any information whatever about that line at any pressure, and the actual curve which Thomas draws becomes nothing more than a sheer guess, than which even Knoblauch's tremendous extrapolation—which is at least a rational guess—is preferable. In the second place practically all of the 31 values fit Knoblauch's curves within their limit of error. As the last column of table 1 shows, Thomas' values average only about 2½ per cent higher than Knoblauch's curves. It should be noticed that the direction of this deviation is that which one would expect on the wet steam theory, for it is probable that not only the saturation tests but all those at low superheats would be affected by this source of error, the amount of wetness present diminishing with increasing superheat. It would follow that C_p would run too high, and this is just what it seems to do.

SUMMARY

9 (*a*) Thomas almost certainly had wet steam in his saturation tests and possibly in many of his other tests; (*b*) if his data are recomputed in such a way as to minimize this source of error, the remaining points give no evidence whatever as to the shape of the saturation line, and very little as to the shape of any of the lines in the usual C_p^1

diagram; (*c*) on the other hand, regarded as isolated points, they agree surprisingly well with Knoblauch's extrapolated curves, even at the high pressures; and (*d*), their deviations from these curves are almost all in the direction which the wet steam theory predicts;

TABLE 1

Tests	Pressure	Saturated temperature Degrees fahr.	Average Temperature Degrees fahr.	*Cp*	*Cp* Knoblauch	Difference Per cent
5–2	7	177	266	0.468	0.462	+1.3
6–3			302	0.470	0.463	+1.5
7–4			365	0.472	0.464	+1.7
12–9	20	228	318	0.478	0.472	+1.2
13–10			354	0.474	0.471	+0.6
14–11			417	0.476	0.471	+1.1
18–16	35	259	331	0.502	0.483	+3.9
19–17			367	0.474	0.480	−1.2
22–20			484	0.478	0.476	+0.4
27–24	55	287	377	0.506	0.493	+2.6
28–25			413	0.493	0.488	+1.0
29–26			476	0.482	0.483	−0.2
34–31	75	308	397	0.512	0.503	+1.8
35–32			433	0.508	0.495	+2.6
36–33			496	0.495	0.487	+1.6
42–40	115	338	446	0.527	0.510	+3.3
43–41			482	0.531	0.500	+6.2
44–42			545	0.491	0.489	+0.4
48–47	165	366	419	0.559	0.562	−0.5
51–49			509	0.535	0.504	+6.1
52–50			572	0.482	0.494	−2.4
57–54	215	388	478	0.550	0.532	+3.4
58–55			514	0.555	0.513	+8.2
59–56			576	0.512	0.500	+2.4
63–61	300	417	489	0.559	0.555	+0.7
64–62			525	0.554	0.521	+6.3
65–63			561	0.550	0.510	+7.8
75–72	500	467	522	0.607	0.624	−2.7
74–73			522	0.625	0.624	+0.2
79–77			675	0.531	0.513	+3.5
79–78			693	0.512	0.511	+0.2

therefore, (*e*) it is unwise, at the present time to attempt to replace Knoblauch's values of C_p as originally published by Thomas' values, or by any compromise based on Thomas' values; and (*f*), the only

modification of Knoblauch's values that can be made with any certainty is that which Professor Heck suggests in the region of very high superheats.

DR. HENRY T. EDDY It would seem to be extremely desirable that Professor Thomas or some other experimenter should introduce a throttling calorimeter into the highly perfected Thomas calorimeter and make such investigations as to reconcile the results reached by those two different methods. Could that be done the results would have a conclusiveness now unattainable. By doing this Professor Thomas would add greatly to the debt the profession owes him for the exceedingly valuable researches he has already completed.

PROF. C. C. THOMAS A new series of experiments upon the specific heat of superheated steam is now in progress under the writer's direction at the University of Wisconsin, and it is expected that the results of these experiments will throw important light upon the question of the relative accuracy of the investigations already completed. The present experiments are being made by an entirely different method from that employed heretofore, and under conditions thought to be especially favorable to obtaining exceedingly accurate results. The writer hopes to be able to present these further results as soon as the experiments are completed and worked up.

CLUTCHES

By Henry Souther, Published in May Proceedings

Mr. B. D. Gray Mr. Souther lays particular stress upon the necessity for copious lubrication and extreme care in the use of the multiple disk clutch. I am not prepared to state in a general way that lubrication is not essential to its satisfactory operation, as there may be clutches of this type, improperly designed, which require a great deal of attention in the way of lubrication. I will state, however, that the clutch with which I am most familiar, and to which I believe Mr. Souther refers in Par. 113 and 114, is not at all sensitive to the question of lubrication, and this is due to three things: first, design; second, quality of materials used; third, correct fitting.

2 I do not mean that the proper materials are very expensive or difficult to procure, but quite the reverse. The steel, for example, is commercial stock and can be obtained from any plate mill manufacturing crucible sheet. The bronze, while of a special composition, is also manufactured commercially. With proper tool equipment there is no difficulty about the fitting up in assembling, and beginning with correct design it becomes simply a commercial proposition. Oils of different viscosities for varying temperatures are not necessary, nor is it necessary to watch carefully the amount of lubrication, though care exercised in this direction naturally tends to lengthen the life of the disks. It is quite the usual thing for this type of clutch to run 25 000 to 30 000 miles with a reasonable amount of attention without renewals, and I doubt very much if even the most approved type of cone clutch will do better.

3 The extreme smoothness of operation of this particular clutch, together with its low inertia, makes it most desirable for use in conjunction with clash gears. The following data may be interesting as supplementary to Mr. Souther's short description of this type of clutch:

Inside diameter, 6.42 in. [163 mm.]
Outside diameter, 7.32 in. [186 mm.]
Area, 9.77 sq. in.
Thickness of bronze disk, 0.058 in.

Thickness of steel disk, 0.042 in.
Spring pressure 22 and 40 h.p. cars, 250.0 lb.
Spring pressure 60 h.p. cars, 300.0 lb.
Pressure per sq. in. 22 and 40 h.p. cars, 25.6 lb.
Pressure per sq. in. 60 h.p. cars, 28.6 lb.
Number of disks.
22 h.p., 12 steel 13 bronze.
40 h.p., 24 steel 25 bronze.
60 h.p., 24 steel 25 bronze.
Total area.
22 h.p., 233.5 sq. in.
40 h.p., 467.0 sq. in.
60 h.p., 467.0 sq. in.
Torque at mean radius of clutch at 1000 r.p.m.
22 h.p., 403 lb.
40 h.p., 734 lb.
60 h.p., 1101 lb.
Coefficient of friction necessary to transmit rated power at 1000 r.p.m.
22 h.p., 0.067.
40 h.p., 0.061.
60 h.p., 0.082

4 I have recently had the opportunity to try a cone clutch, which was very much the smoothest in operation of any I have seen. The clutch itself was of the ordinary type with about the usual amount of bearing surface, and with an angle of 15 deg. Its extreme softness of action apparently results from the arrangement of springs, of which there are two, one comparatively soft, and the other very much stiffer. In engagement the soft spring comes into play first, and is followed by the stiffer spring after the inertia of the car has been partially overcome. The mileage given by this clutch is remarkable, and I am informed that it has been tested under most severe conditions and without attention. It is possible that the ultimate success of the cone clutch may depend upon some such principle as this.

Prof. Forrest R. Jones I would suggest a modification of the first two sentences of the author's Par. 66, to read as follows: Any automobile clutch must engage *quickly*, smoothly and absolutely without shock *up to the full torque capacity of the motor with certainty of not exceeding this amount of grip by more than a few per cent at most, must not be injured by heating to a high temperature on account of the slipping that must necessarily occur when starting the car, and must be durable,* to be called a success. The italicized portion is the addition to the original sentences.

2 The torque that a given clutch will transmit depends solely on

the pressure between the friction surfaces and the coefficient of friction. The latter is a variable quantity as has been pointed out by M. Souther. It is generally exceedingly variable and always beyond control. The only method of regulating the torque is by variation of the pressure between the friction members.

3 To meet the requirements of a successful clutch, as just stated, *the pressure between the friction surfaces must be regulated automatically* so as to be inversely proportional to the coefficient of friction. That this automatic regulation can be accomplished successfully has been demonstrated by tests upon a clutch, a description of which the writer hopes later to present to the engineering profession.

MR. C. R. GABRIEL The following figures show a few of the oldest and best known clutches as applied to power presses, many of which are in use today and preferred by some users to more recent designs.

2 Fig. 1 shows a type of press that has been in use for about sixty years, known as the Fowler press. The feature of the clutch in this press is that the driving pins are carried in the hub of the flywheel and operated by a sleeve on the outer end of the shaft, the pins engaging an abutment on the shaft collar. This arrangement permits of starting or stopping the shaft at any point of the revolution, and is called for by some users at the present time.

3 Fig. 2 shows the original Stiles clutch. This clutch has a spring actuated bolt and retaining latch carried in the hub of the fly wheel, the bolt latch being released by the action of the cam carried in the bracket below the shaft collar, which is connected to the foot treadle rod. Depressing the treadle allows the bolt to engage the recess in the shaft collar; a revolution of the shaft follows, and is automatically stopped if the foot has been removed from the treadle. Continued pressure on the treadle results in continuous strokes of the press. This clutch also permits of the shaft being rotated by means of a crank applied to the shaft on the connection end, without stopping the fly wheel, a very convenient feature in setting tools. Also more than one bolt may be carried by the fly wheel, which results in a marked saving of time on work when the press is stopped at each stroke, as the arc of rotation of the wheel will be in proportion to the number of bolts used, and the loss of time after the treadle is depressed will be diminished by the same ratio.

4 Fig. 3 shows a safety latch applied to the Stiles clutch, and is designed to prevent repeating. If an operator holds his foot on the treadle for an interval of time greater than is consumed in one revolu-

tion of the shaft, the press will repeat, and many accidents are due to this cause, as the operator attempts to remove or place the work and is caught before the hand can be removed from the dies. This arrange-

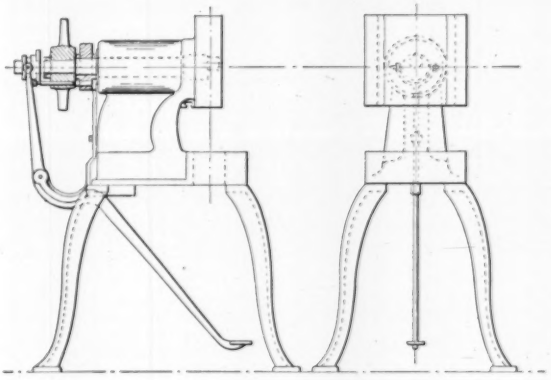

FIG. 1 FOWLER PRESS

ment consists of a type of releasing mechanism. A cam is secured to the shaft collar, and as the shaft rotates, it engages the toe of the hook lever, and forces it into the position indicated by the dotted lines,

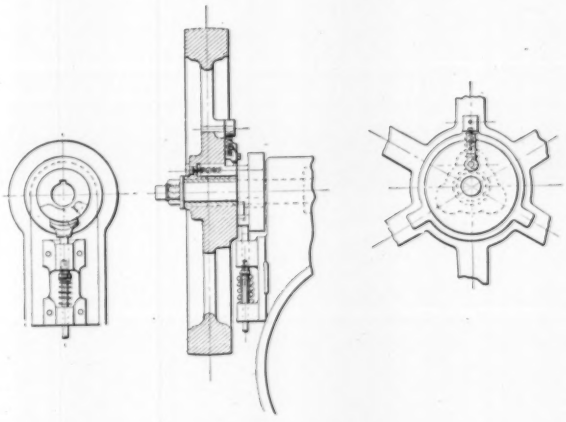

FIG. 2 STILES CLUTCH

thus releasing the clutch cam which is forced upward by the spring and disengages the bolt, stopping the press even though the operator keeps the treadle depressed.

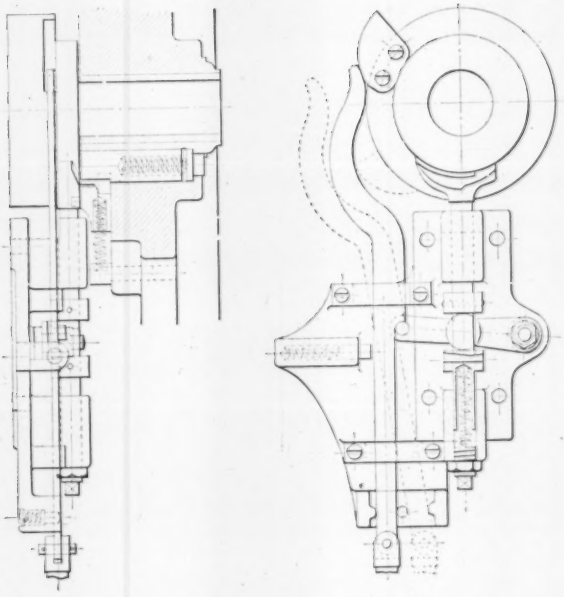

FIG. 3 SAFETY LATCH ON STILES CLUTCH

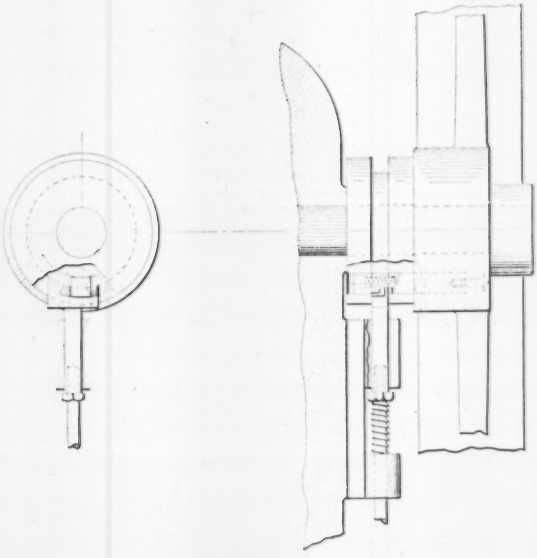

FIG. 4 JOHNSON CLUTCH

5 For continuous running, the hook lever may be shifted to the right as indicated by the dotted lines at the bottom of the bracket; this carries the toe of the lever out of the path of the cam, allowing the hook to remain engaged, and continuous running is obtained by keeping the treadle depressed.

6 Fig. 4 shows the well known Johnson clutch, in very general use today. It differs from the types that have been shown by having the sliding bolt in the shaft. This construction does not permit of the shaft being rotated independent of the wheel, as the bolt is free

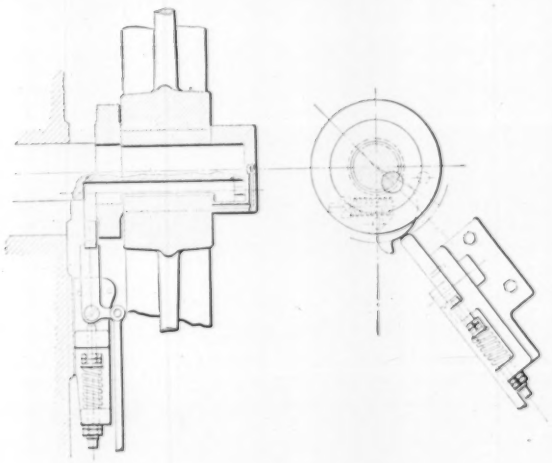

FIG. 5 BLISS CLUTCH

to engage the wheel as soon as it disengages the pull-out cam, which operates when the slide is at the up-stroke.

7 In setting tools it is necessary to remove the belt from the fly wheel and allow the clutch to engage and rotate the shaft by turning the wheel by hand.

8 To save time when the press is to be stopped at each stroke, two or more notches may be made in the wheel hub.

9 Fig. 5 shows the well known Bliss clutch, which has the rolling pin instead of the sliding bolt. This pin is made of tool steel and engages a tool steel striking piece the entire length of the wheel-hub. As the clutch pin is located very close to the axis of the shaft, the velocity and violence of the blow with which the wheel is driven gainst the pin is reduced to a minimum. This assures the smoothness and durability that distinguishes this type of clutch.

10 It has an advantage in that the wheel can be backed up without rotating the shaft which permits of bumping the shaft over the center as is often necessary when the dies become jammed or in trying the tools.

11 Fig. 6 shows the application of the safety latch to the Bliss clutch. As the arrangement is substantially the same as that described for the Stiles clutch, it will not be necessary to take time to go over the details.

12 Fig. 7 shows a type of positive multiple jawed clutch for stamping and forging presses which run at slow speed. The clutch collar

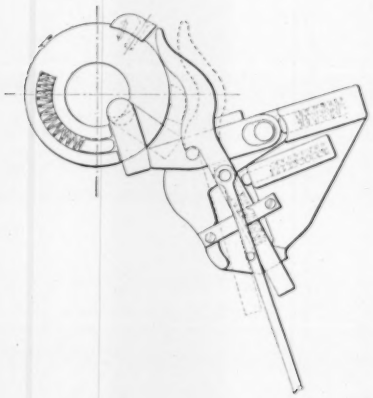

FIG. 6 SAFETY LATCH APPLIED TO BLISS CLUTCH

which is on the outer end of the shaft, is of steel, with teeth engaging the driving member, also of steel and secured to the wheel-hub.

13 The sliding member is fitted to the shaft, which is slabbed off in the manner shown, a construction superior to keys, which become loose with the great strain brought to bear on them. The driven clutch is held out of engagement by means of the sliding bolt in the shaft, operated in the same manner as the Johnson clutch. When the foot treadle is depressed, the cam is withdrawn, and the spring on the shaft end is free to engage the clutch. The weighted lever on the right is employed to insure the separation of the clutch teeth, as the momentum of the shaft in slow running presses is not sufficient to carry the bolt on to the cam far enough to prevent the clutch teeth from clicking after the shaft is at rest.

14 In this arrangement the weighted lever is lifted by means of a cam on the shaft, and at the point of disengagement of the clutch the

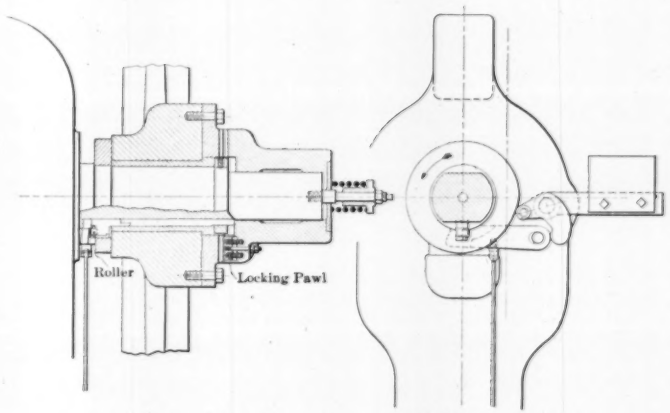

FIG. 7 POSITIVE MULTIPLE JAWED CLUTCH

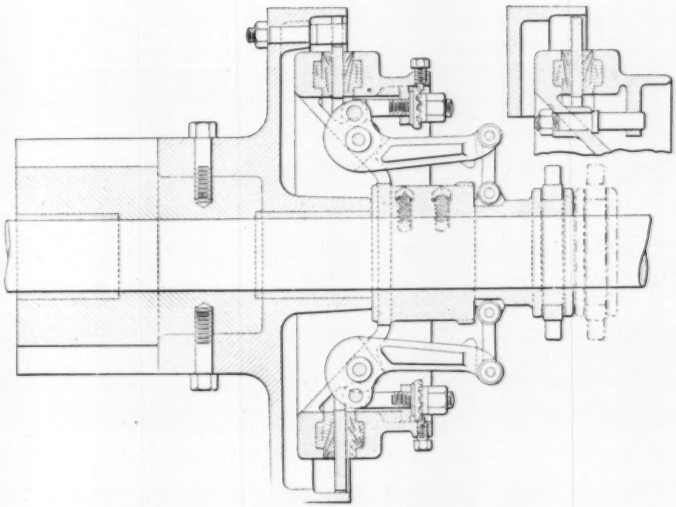

FIG. 8 FRICTION CLUTCH FOR LARGE PRESSES

weight is allowed to fall with sufficient force to drive the bolt cam forward, thus separating the teeth as desired.

15 Fig. 8 shows a type of friction clutch used on large back-geared presses and quite similar to some clutches shown by the author. The friction surfaces are wood against cast iron. The cast iron disk is allowed to float on the studs in the pulley, relieving any radial strains, and the wooden friction rings are mounted on the clutch body, the

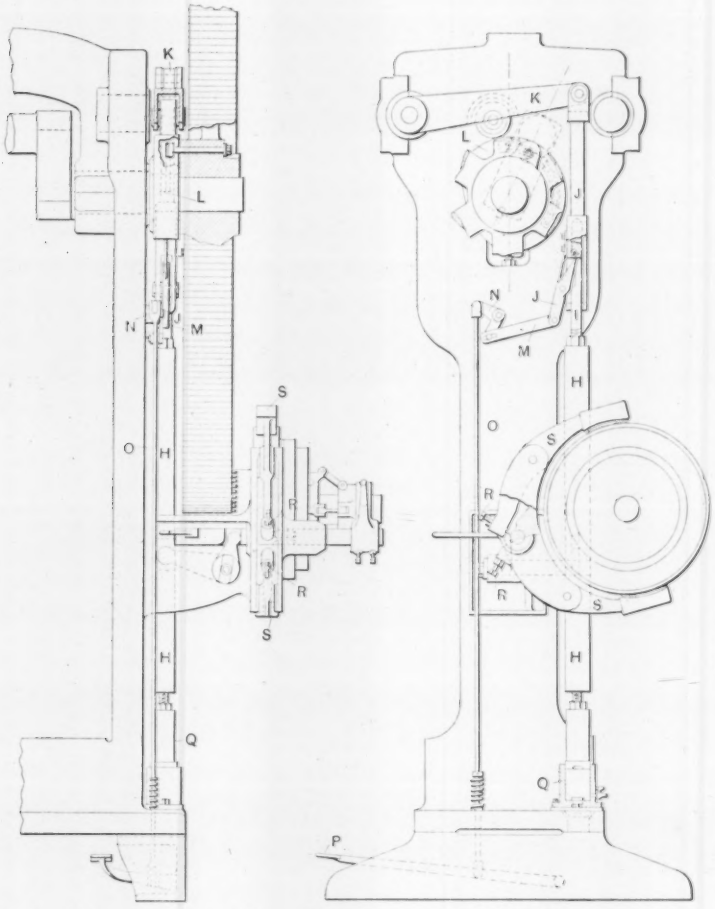

FIG. 9 APPLICATION OF CLUTCH WITH MEANS FOR STOPPING AUTOMATICALLY

clamping ring being operated by the double toggles connected to the sliding sleeve on the shaft. The shaft runs continuously with the pinion, being at rest when the press is stopped.

16 The action of this clutch where it is applied to stop automatically at the completion of each stroke of the press is shown in Fig. 9.

17 The cam L placed on the main shaft inside the gear automatically disengages the clutch. It is held in position by a bolt passing through the hub of the gear. By this means the cam can be set forward or back to insure the press stopping at the proper point.

18 The vertical rod I with the weight H attached is raised by means of the latch J. When the main shaft turns over, the lifter K drops, allowing the latch J to engage with the rod I. When K rises it takes the rod I with it, thus throwing the clutch out of action.

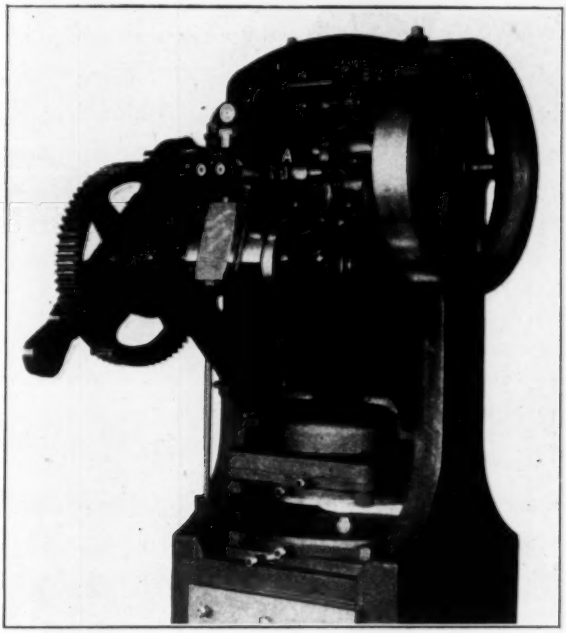

FIG. 10 SPECIAL CLUTCH MECHANISM—CLUTCH AT A

The upper end of the latch J is hardened tool steel and a piece of hardened tool steel is inserted in the rod I for the latch to lift against.

19 In order to start the press, the treadle P is depressed. A link M is attached to the latch and connected with the bell-crank N, which in turn is connected with the treadle P by the rod O, the forward end of the link M being slotted to permit the latch to fully engage the lifter shoe in rod I.

20 An air dashpot Q is provided below the weight H in order to allow the weight to drop easily without shock, and an air cock is

provided in the dashpot, by means of which the proper degree of cushion may be obtained.

21 In order to stop the press promptly and hold the shaft securely at the top of the stroke, the brake arms S are provided. The pressure on the brake arms S can be regulated by the set screws R which can be set sufficiently tight to stop the main crank in the proper position.

22 Fig. 10 and 11 show a novelty in press construction. The problem involved the use of special clutch mechanism, combined with a new mechanical movement. In this press, the slide must

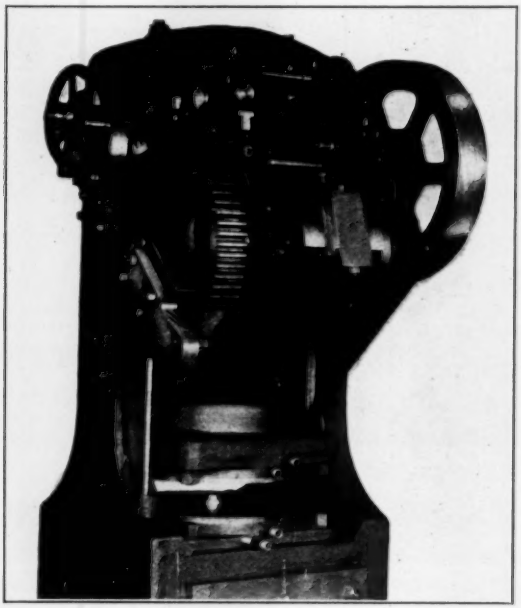

FIG. 11 VIEW SHOWING LARGE CAM TEETH FOR STARTING AND STOPPING ACTION

stop at the down position, under the maximum pressure, which necessitates disengaging the driving clutch at this point. To accomplish this successfully, it is necessary to relieve the clutch from strain that the teeth may be unlocked without injury.

23 The driving member of the clutch is secured to the fly wheel shaft, and the driven member is fitted to slide on keys in the pinion shaft. The teeth are held out of engagement by means of a cam made

in the body of the sliding member and locked by means of a plunger pin operated by the treadle.

24 The feature of the mechanical movement is its starting and stopping action without shock, operating as follows: the gear mounted on the crank shaft is provided with two cam teeth, diametrically opposed, and the cams are designed to work between two rolls on the disk mounted on the end of the pinion shaft. The gear has several teeth removed back of each cam, allowing the action of the rolls on the cam to start the gear and thus the angular velocity of the gear is gradually accelerated, until the pitch line velocity of the gear has attained the same speed as the pinion, when the pinion teeth enter into mesh and carry the gear around to the point where the opposite cam controls the stopping without shock, the pinion shaft being relieved of all tortional strain, permitting the clutch to be thrown out without difficulty.

25 This press is arranged to stop at the down stroke, applying a pressure of 40 tons to the work for a length of time determined by the automatic tripping mechanism, which time can be varied by means of a series of change gears. This pressure is secured by having the lower die rest on a nest of heavy springs, which can be energized from below by means of a worm and wheel mounted on a sun gear; this in turn driving pinions on the screws employed for loading the springs to any desired amount.

26 The automatic tripping is accomplished through the action of a cam on the crank shaft, which engages a clutch at the instant the slide is down, this clutch being driven by means of gears from the continuously running driving shaft. Through the gearing the main driving clutch is tripped by the action of a trip-dog carried on a worm wheel which makes one revolution during the interval the slide is down.

A JOURNAL FRICTION MEASURING MACHINE

By Henry Hess, Published in January Proceedings

The Author Mr. Peirce's experience with ball bearings illustrates the fact, not yet generally recognized, that well made ball bearings are capable of abuse far beyond the endurance capacity of a sliding journal. Take for instance the footsteps of his rubbing beds; the arrangement usually employed is the hardened steel washer step running in oil and surrounded by a water cooling bath; but quite aside from the frictional losses, such footsteps are a source of more or less continuous trouble. A ball bearing, however, installed to carry 4 tons, is carrying over four times this load, and so successfully that the new, properly dimensioned, ball steps ordered when the error in the weight specifications was recognized have not yet been installed.

2 Mr. Peirce refers also to the ball bearings on his carborundum spindles. The exceedingly difficult character of this service will be recognized by every engineer familiar with the hammering effect of high speed parts not in perfect running balance. In this case we have a spindle carrying a series of carborundum discs 16 in. in diameter and combined to make up a cutting face 6 ft. in length, the discs strung on a cast iron spider. By the aid of balancing ways a good standing balance is secured, but a good running balance only when the fates are propitious. As an additional difficulty, ball bearings not being provided for in the original design, such dimensions were given them as the existing parts permitted, after a trial on plain journals had failed, with the expectation that frequent renewal would be necessary. Yet with all these disadvantages, renewal of the balls alone was necessary after six months continuous operation. This illustrates one of the decided advantages of the ball bearing. In the plain journal wear affects spindle and box, while in the ball bearing the balls and races are parts attached to the shaft, and their removal and replacement is all that is required to restore the journal to its pristine condition; no machining of any parts is required, but only reassemblage of relatively cheap parts.

3 The author desires to call the attention of engineers interested in the development of their art to the machines developed by Mr. Peirce for the working of marble and other stones. The mason's craft is very old and has developed but little during the ages, but Mr. Peirce's machines have so revolutionized processes as to multiply the output in some lines a thousandfold. The plant, that of Wm. Bradley and Sons, is situated on Long Island within convenient reach of the 34th St. bridge or ferry, and is, no doubt, open to inspection.

4 Professor Brashear is interested in the early use of ball bearings. Their use goes far back of the Allegheny Observatory erection in 1856. The author has been informed that a cast iron sheave, supposed to have been installed over two centuries ago, is still to be seen on the quay at Dieppe, France. All records of its installation have been lost, and it has not been in use for over a century. The hub is broken, exposing to view part of the balls.

5 Whether a simpler machine for testing ordinary journals is desirable depends altogether upon the accuracy and refinement required. To determine the frictional qualities by actual measurement of the co-efficient of friction is possible on various existing machines of other types; since the friction of plain journals is relatively large, machines of lesser accuracy will answer for them. It must not be assumed, however, that the great delicacy of the machine described implies a lack of robustness—quite the reverse. Bearings have frequently been run to the point of total and violent breakdown at high speeds and under loads of 15 000 lb. without any damage whatever to the machine.

6 Professor Benjamin's difficulty in understanding the way in which the load is applied is one that the author cannot assume complete responsibility for; he must transfer at least a part to the Meetings Committee which rejected for illustration the cross-sectional drawings that originally accompanied the manuscript. Briefly, a spindle of very large size, compared with the loads to be carried, is mounted on heavy ball bearings (that at one end employs 1⅝ in. balls), and driven by tight and loose pulleys from a variable speed reversible motor. The front end of the spindle is bored out to receive a taper arbor of which a number are provided to suit the various bearings to be tested. The inner race of the test bearing is mounted on the overhanging nose of this taper arbor, while a bush in the yoke suspended from the rod carried to the loading beams receives the outer race. The system of weighing levers clearly shown in the illustrations pull upward on the bearing and so load it. Professor Benjamin's demand

that the insulation of the bearing to be tested from any other bearings in the machine be as complete as possible is fully met so far as the resistance of these other bearings to friction is concerned. In that respect, isolation is absolute in this machine. Whether the frictional resistance of the spindle journal be high or low is absolutely immaterial. Ball bearings have been chosen simply because of their easy-running qualities and greater reliability under the extreme speed and load; manifestly it would be difficult to run a spindle 5.5 in. in diameter at 2500 r.p.m. under 15 000 lb. load in a plain journal.

7 Heat isolation, though not quite absolute, is also very good. For very accurate work the spindle is run at proper speed and load until the temperature of the machine journal is constant before the test bearing is put in place. The lower portion is submerged in a pan of oil, of which it carries a portion around with it, throwing it off in a narrow stream. A sensitive thermometer is placed in the path of this stream. While the temperature of this stream is not absolutely that of the journal it is very nearly so, quite nearly enough for purposes of comparison; the method is as accurate as any with which the author is familiar.

8 When the endurance of a bearing is to be tested, a much simpler machine can be extemporized from wooden beams, plain shafting and hangers, with a very simple loading lever, and answering every purpose.

9 The occasion of the design of the machine described was the observation of journal phenomena quite beyond the capabilities of the usual friction measuring machine, without limiting its load capacity, but rather while carrying that to a higher point than usual. While the author has so far confined the use of this machine to an investigation of ball and roller bearings, being primarily interested in carrying these to the highest attainable stage of perfection, he does contemplate a later investigation of plain journals, and hopes, because of the greater refinement and accuracy of this machine, to find the cause for certain phenomena in sliding journals and lubricants for which the usual apparatus fails to account.

SOME PITOT TUBE STUDIES

By Profs. W. B. Gregory and E. W. Schoder, Published in May Proceedings

The Authors There is abundant experimental evidence showing that the suction effect due to reversing a Pitot tube is considerably affected by the shape of the tube, as Dr. Moss states in his discussion.

2 However, the writers would hardly designate the downstream readings as "illusory," to use Prof. Eddy's adjective. No doubt there is mystery in all of Nature's phenomena. Moreover, in the experiments described in the paper there are noticeable individual departures (in column 7 of Table 1) from the average value 1.133 for $\frac{v_1}{v_1}$. Still the mean value for any one of the five traverses is within less than 3 per cent of 1.133. This speaks for itself.

3 Prof. Eddy's statement concerning depth of immersion and the drawing of air into the downstream opening of the Pitot tube may have some application to open channel conditions near the surface, but is not applicable to a Pitot tube in a pipe under pressure. There seems to be no reason why the suction head should not vary as a function of the velocity far beyond the range investigated by the writers. This includes velocities as high as 20 ft. per second. The limiting value in any extreme case would occur when a vacuum would be produced at the downstream opening. But for all velocities met with in practice the experimental evidence indicates that in closed pipes the suction head does vary as a definite function of the velocity.

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EXCHANGES

NORTHERN RAILWAY CLUB. *Official Proceedings, August and July, 1908. Duluth, 1908. Vol. 3, No. 9 and 10.* 8vo, paper.

PATENT OFFICE LIBRARY. Subject Lists. Works of Reference, Biography, Bibliography, the Auxiliary Historical Sciences, etc. *London, 1908.* 16mo, paper, 336 p.

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EMPLOYMENT BULLETIN

The Society has always considered it a special obligation and pleasant duty to be the medium of securing better positions for its members. The Secretary gives this his personal attention and is most anxious to receive requests both for positions and for men available. Notices are not repeated except upon special request. Copy for notices in this Bulletin should be received before the 15th of the month. The list of men available is made up of members of the Society, and these are on file with the names of other good men not members of the Society who are capable of filling responsible positions. Information will be sent upon application.

POSITIONS AVAILABLE

033 Services of a competent draftsman, technical graduate in mechanical engineering preferred, familiar with power plant and heating design, ventilation and the ordinary routine electrical requirements for electrical motor installations. $125 to $150 per month to start; location San Francisco.

034 Competent engineer to prepare general designs for draw, lift and bascule bridge machinery; must have technical education and sound experience in drawing room and shop. Should possess originality to certain extent. Location middle West.

035 Wanted by firm of heating contractors, a young man who thoroughly understands heating and ventilating work, ability to make estimates and consult with architects. Location, Toronto, Canada.

036 First class civil engineer for street railway track construction and maintenance and repair work. Competent to do work such as described, must have the qualification of speaking Spanish fluently and correctly. Location Mexico City.

MEN AVAILABLE

152 Position desired in office or factory situated in or near New York. Eighteen months practical shop work, one year office training.

153 Junior member five years practical experience in mill construction, designing special machinery and piping layouts for power plants.

154 Electrical Engineer and Superintendent of construction, eight years in charge of design, construction and operation of electrical refrigeration and ice-making plants, responsible charge. Experience covers period of eighteen years.

155 Member; thorough business training, up-to-date factory manager, good executive and organizer; competent in manufacturing medium and light machinery or purchasing department; fully qualified to fill position of responsibility. Patentee many devices. Willing to go abroad.

156 Member, technical graduate, 20 years experience, ten years in charge on design, construction and maintenance, industrial plants, reinforced concrete buildings, steam plants, crushing, hoisting, conveying and transmission machinery.

157 Mechanical and electrical engineer, age 37, Cornell graduate, experienced in general building construction, power plant design, construction and operation.

158 Member, ten years experience in design and construction of gas and electric plants, seeks position.

159 Member, experienced in the design, construction, erection, operation and testing of underfeed and overfeed stokers applied to boiler furnaces, dryers, kilns, and metallurgical furnaces, desires position as engineer or engineering salesman.

160 M. E. Stevens, experienced in power plant construction, factory equipment and maintenance, thoroughly acquainted with up to date methods of factory management and accounting. Position as superintendent of maintenance, construction, or as mechanical engineer with contracting firm.

161 Member, technical graduate, thirty-one years old, eight years varied experience, desires connection with firm as assistant to chief engineer, or other position of responsibility; would represent some firm desiring a New York City connection.

162 Junior member, graduate of one of the leading Eastern universities, desires position in the East. Over four years' experience in designing, testing, selling and experimental work; last year devoted to experimental work in connection with the uses of denatured alcohol as a fuel.

163 Mechanical engineer, married, with thorough drafting room experience in power station design and construction work. At present employed as superintendent of construction, wishes to make a change. New York preferred but will go anywhere.

164 Mechanical superintendent, works manager, technical and practical training, up-to-date in economical maintenance of labor and machinery and the generation and distribution of power. Executive ability. Design of appliances, tools and automatic machinery.

165 Superintendent or General Manager. Twenty years experience in machine shop, iron and brass foundry management, largely on hand, triplex electric and steam pumps, designing, manufacturing and selling. Thoroughly experienced with modern machine tools, gigs, and fixtures for interchangeable work; mixtures for gray iron and for brass and bronze castings; metal pattern and molding machine equipment; accounting and cost-keeping. American, Technical Graduate. Practical executive, very successful in reorganizing and modernizing for low cost production.

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November 13, 33 W. 39th St., New York, 8 p.m. Secy., R. W. Pope. Paper: Electrical Heating, W. A. Hadaway, Jr.

AMERICAN GEOGRAPHICAL SOCIETY

November 24, 29 W. 39th St., New York, 8 p.m. Secy., A. A. Raven.

AMERICAN RAILWAY ASSOCIATION

November 18, annual meeting, Chicago, Ill. Secy., W. F. Allen, 24 Park Pl., New York.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

November 10, 29 W. 39th St., New York, 8 p.m. December 1–4, annual meeting. Secy., Calvin W. Rice.

AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

November 30–December 1, annual meeting, 29 W. 39th St., New York. Secy., W. H. Ross, 154 Nassau St.

BLUE ROOM ENGINEERING SOCIETY

November 5, December 3, 29 W. 39th St., New York, 8 p.m. Secy., W. D. Sprague.

BOSTON SOCIETY OF CIVIL ENGINEERS

November 18, monthly meeting, Tremont Temple. Secy., S. E. Tinkham, 60 City Hall.

BROOKLYN ENGINEERS CLUB

November 12, 197 Montague St. Secy., J. Strachan. Paper: Some Features of the Bridges of the Harlem River Branch, N. Y., N. H. and H. R. R., H. C. Keith.

CANADIAN SOCIETY OF CIVIL ENGINEERS

November 12, 19, 26, December 3, Montreal, Que. Secy., Clement H. McLeod, 413 Dorchester St., W.

CAR FOREMEN'S ASSOCIATION OF CHICAGO

November 9. Secy., Aaron Kline, 326 N. 50th St.

CENTRAL ASSOCIATION OF RAILROAD OFFICERS

November 9, Kansas City. Secy., J. H. Ashley, Gumbel Bldg.

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November 12, Toledo, O. Secy., H. M. Elliot.

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November 19, Lima House, Lima, O. Secy., A. L. Neereamer, 306 Traction Terminal Building, Indianapolis, Ind.

CENTRAL RAILWAY AND ENGINEERING CLUB OF CANADA

November 17, Rossin House, Toronto, Ont. Secy., C. L. Worth, Room 409, Union Station. Paper: The Electrification of Sarnia Tunnel, W. D. Hall.

CENTRAL RAILWAY CLUB

November 13, Buffalo, N. Y., 2 p.m. Secy., H. D. Vought, 95 Liberty St., New York.

CLEVELAND ENGINEERING SOCIETY

November 10, monthly meeting, Caxton Building. Secy., Joe C. Beardsley.

COLORADO SCIENTIFIC SOCIETY

November 7, December 5, Denver. December 19, annual meeting. Secy., Dr. W. A. Johnston, 801 Symes Bldg.

ENGINEERING ASSOCIATION OF THE SOUTH

November 17, monthly meeting, Nashville Section, Carnegie Library Bldg. Section Secy., H. H. Trabue, Berry Block, Nashville.

ENGINEERING SOCIETY OF THE STATE UNIVERSITY OF IOWA

December 1, monthly meeting, Iowa City, Ia. Dean, Wm. G. Raymond.

ENGINEERS AND ARCHITECTS' CLUB OF LOUISVILLE, KENTUCKY

November 16, monthly meeting, 303 Norton Bldg. Secy., Pierce Butler.

ENGINEERS' CLUB OF BALTIMORE

November 7. Secy., R. K. Compton, City Hall.

ENGINEERS' CLUB OF CENTRAL PENNSYLVANIA

December 1, monthly meeting, Gilbert Bldg., Harrisburg. January 5, 1909, annual meeting. Secy., E. R. Dasher.

ENGINEERS' CLUB OF CINCINNATI

November 19, 25 E. 8th St. Secy., E. A. Gast, P. O. Box 333.

ENGINEERS' CLUB OF PHILADELPHIA

November 7. Secy., H. G. Perring. Papers: The Foundation of the United States Naval Station at Annapolis, H. W. Latta; Should Engineers, Architects and Builders be Licensed, F. G. Mylertz.

ENGINEERS' SOCIETY OF MILWAUKEE

November 11, monthly meeting. June 9, annual meeting. Secy., W. Fay Martin, 396 Bradford Ave.

EXPLORERS CLUB

November 6, December 4, 29 W. 39th St., New York, 8.30 p.m. Secy., H. C. Walsh.

FRANKLIN INSTITUTE

November 16, opening of the autumn course. Secy., Wm. H. Wahl, 15 S. 7th St., Philadelphia, Pa. Paper: The Measurement of Sound and its Practical Applications, A. G. Webster.

GENERAL MANAGERS' ASSOCIATION OF CHICAGO

November 19, Dearborn Sta. Secy., H. Deeming.

GENERAL SUPERINTENDENTS' ASSOCIATION

November 18, Chicago, Ill. Secy., H. D. Judson, C. B. & Q. R. R., Chicago.

ILLUMINATING ENGINEERING SOCIETY

November 12, 29 W. 39th St., New York, 8 p.m. Secy., P. S. Millar.

IOWA RAILWAY CLUB

November 13, Des Moines. Secy., W. B. Harrison, Union Sta.

LOUISIANA ENGINEERING SOCIETY

November 9, monthly meeting, 323 Hibernia Bldg., New Orleans. January 9, 1909, annual meeting, New Orleans. Secy., L. C. Datz, 323 Hibernia Bldg.

MASSACHUSETTS STREET RAILWAY ASSOCIATION

November 11, Boston. Secy., Charles S. Clark, 70 Kilby St.

MUNICIPAL ENGINEERS OF THE CITY OF NEW YORK

November 25, 29 W. 39th St., 8:15 p.m. Secy., C. D. Pollock. Paper: Waterproofing an Engineering Problem, Myron H. Lewis.

NATIONAL SOCIETY FOR THE PROMOTION OF INDUSTRIAL EDUCATION

November 19–21, annual meeting at Atlanta, Ga. Secy., James P. Haney, 546 Fifth Ave., New York. Papers: Industrial Education as an Essential Factor in our National Prosperity, James Wilson, E. E. Brown, Carroll D. Wright; Industrial Training through the Apprentice System, E. P. Bullard; Promotion of Industrial Education by Means of Trade Schools, George N. Carman, J. M. Shrigley; Moral and Material Benefits of Industrial Education to the Nation, G. G. Jordon, Mrs. B. B. Munford; Industrial Education in the Public Schools, Thomas M. Balliet, L. D. Harvey.

NEW ENGLAND RAILROAD CLUB

November 10, monthly meeting, Boston, Mass. Secy., Geo. H. Frazier, 10 Oliver St., Boston.

NEW ENGLAND STREET RAILWAY CLUB

November 26, American House, Boston, Mass. March 25, 1909, annual meeting. Secy., John J. Lane, 12 Pearl St.

NEW ENGLAND WATER WORKS ASSOCIATION

November 11, regular meeting. Secy., Willard Kent, Tremont Temple, Boston, Mass.

NEW YORK RAILROAD CLUB

November 20, monthly meeting, 29 West 39th St. Secy., H. D. Vought, 95 Liberty St.

NEW YORK SOCIETY OF ACCOUNTANTS AND BOOKKEEPERS

November 10, 17, 24, December 1, 29 W. 39th St., 8 p.m. Secy., T. L. Woolhouse.

NEW YORK TELEPHONE SOCIETY

November 17, 29 W. 39th St., 8 p.m. Secy., T. H. Laurence.

NORTHERN RAILWAY CLUB

November 28, Commercial Club Rooms, Duluth, Minn. Secy., C. L. Kennedy.

NORTH WEST RAILWAY CLUB

November 10, St. Paul, Minn. Secy., T. W. Flannagan, Soo Line, Minneapolis, Minn.

OHIO SOCIETY OF MECHANICAL, ELECTRICAL AND STEAM ENGINEERS

November 20–21, Toledo. Secy., David Gaehr, 1135 Schofield Bldg., Cleveland. Papers: The New Engineering Laboratory, Profs. F. C. Caldwell and E. A. Hitchcock of Ohio State University; description of The Columbus Municipal Electric Light Plant, G. H. Gamper; Underground Heat Insulation of Steam Piping, H. K. Gillette; description of the Toledo Filtration Plant and Waterworks, Supt. Taylor; Refrigeration, Thos. Baker.

PACIFIC NORTHWEST SOCIETY OF ENGINEERS

November 7, December 5, monthly meetings, Lowman Bldg., Seattle, Wash. Secy., Arthur H. Dimock, City Engineer's Office. Paper: Sluicing Operations on Topographers Hill, E. W. Commings; December 5, Seattle Sea Wall, D. W. McMorris.

PROVIDENCE ASSOCIATION OF MECHANICAL ENGINEERS

November 24, monthly meeting, 48 Snow St. June 22, 1909, annual meeting. Secy., T. M. Phetteplace.

PURDUE MECHANICAL ENGINEERING SOCIETY

November 11, 25, Purdue University, Lafayette, Ind., 6:30 p.m. Secy., L. B. Miller.

RAILWAY CLUB OF PITTSBURGH

November 27, annual meeting, Monongahela House, Pittsburg, Pa., 8 p.m. Secy., J. D. Conway, Gen. Office, P. & L. E. R. R.

RENSSELAER SOCIETY OF ENGINEERS

November 6, 20, December 4, 257 Broadway, Troy, N. Y. Secy., R. S. Furber.

RICHMOND RAILWAY CLUB

November 9. Secy., F. O. Robinson, C. & O. Railway.

ROADMASTERS' AND MAINTENANCE OF WAY ASSOCIATION

November 10–12, annual meeting, Milwaukee, Wis. Secy., Walter E. Emery, W. Chicago, Ill.

ROAD AND TRACK SUPPLY ASSOCIATION

November 10–12, Milwaukee, Wis.. Secy., John W. Reynolds, 160 Harrison St., Chicago, Ill.

ROCHESTER ENGINEERING SOCIETY

November 13, monthly meeting. Secy., John F. Skinner, 54 City Hall.

SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

November 19–20, annual meeting, 29 W. 39th St., New York. Secy., Wm. J. Baxter, Bldg. No. 6, Navy Yard, Brooklyn. Papers: The War Eagle, C. H. Cramp; Practical Methods of Conducting Trials of Vessels, E. A. Stevens; Influence of Midship Section on Resistance of Ships, D. W. Taylor; Longitudinal Displacement and Effect on Resistance, H. C. Sadler; Further Analysis of Propeller Experiments, C. H. Crane; Deviation of Compass aboard Steel Ships, its Avoidance and Correction, L. H. Chandler; Free Water Ballast, T. G. Roberts; Recent Inventions as Applied to Modern Steamships, W. C. Wallace. (Friday) Service Test on Steamship Harvard, C. H. Peabody; U. S Scout Cruiser Chester Fitted with Parsons Turbines, C. P. Wetherbee; The Steam Turbine, J. W. Powell; Shipbuilding on the Great Lakes, Robert Curr; The Steamer Commonwealth, J. H. Gardner, W. T. Berry; Fire Boats, C. C. West; Sea Going Suction Dredges, T. M. Cornbrooks; British International Trophy Race of 1908, W. P. Stephens; Transportation of Submarines, W. J. Baxter.

SOUTHERN AND SOUTHWESTERN RAILWAY CLUB

November 19, annual meeting, Atlanta, Ga. Secy., A. J. Merrill, 218 Prudential Bldg., Atlanta.

ST. LOUIS RAILWAY CLUB

November 13, monthly meeting. Secy., B. W. Frauenthal.

TECHNICAL SOCIETY OF BROOKLYN

November 6, semi-monthly meeting, Arion Hall, Arion Place, Brooklyn, N. Y.

TECHNICAL SOCIETY OF THE PACIFIC COAST

December 4, bi-monthly meeting at San Francisco, Cal. Secy., Otto von Geldern, 1978 Broadway.

TECHNOLOGY CLUB OF SYRACUSE

November 10, monthly meeting, 502 The Bastable Blk., 8 p.m. Secy., Geo. D. Babcock. Paper: Coast Defence and Effect of High Explosives on Armor Plate, C. S. Jamieson.

WASHINGTON SOCIETY OF ENGINEERS

November 24, Hubbard Memorial Hall, 8 p.m. Secy., John F. Hoyt, 1330 F St. N. W. Paper: Utility of the Water Resources of the Hawaiian Islands, F. H. Newell.

WESTERN ELECTRIC CLUB

November 10, 29 W. 39th St., New York, 8 p.m. Secy., J. W. Dietz.

WESTERN RAILWAY CLUB

November 17, monthly meeting, Auditorium Hotel, Chicago, Ill., 8 p.m. Secy., Jos. W. Taylor, 390 Old Colony Bldg.

WESTERN SOCIETY OF ENGINEERS

November 18, December 2, bi-weekly meetings, 1737 Monadnock Blk., Chicago, Ill. January 5, 1909, annual meeting. Secy., J. H. Warder. Papers: Work of the Engineering Staff of the Wisconsin Tax and Rate Commission, Professor Pence.

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1908

On a Standard Tonnage Basis for Refrigeration

D. S. JACOBUS — G. T. VOORHEES
A. P. TRAUTWEIN — PHILIP DE C. BALL
E. F. MILLER

On Society History

JOHN E. SWEET — H. H. SUPLEE
CHARLES WALLACE HUNT

On Affiliated Societies

F. R. HUTTON, *Chairman* — F. W. TAYLOR
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On International Standard for Pipe Threads

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